AO-02-01-OSS-007

Proposal Cover Page

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AO 02-OSS-01 - Solar Dynamics Observatory (SDO) and Related Missions of Opportunity

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Institution Authorization

Name of Authorizing Official:

Title:

Institution:

Signature and Date:

Full Title
Atmospheric Imaging Assembly (AIA)for Solar Dynamics Observatory (SDO)

Short Title: AIA for SDO

Budget Information

Total NASA OSS Cost (in RY $):
$ 62,120,000

Total NASA OSS Cost (in 2002 $):
$ 56,766,000

Total Investigation Cost (in RY $, including contributions):
$ 78,360,000

Total Investigation Cost (in 2002 $, including contributions):
$ 71,008,000

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NASA Grant or Contract Number of any current NASA award that the PI holds that is a logical predecessor of the newly proposed work
TRACE - NAS5-38099

Type of Proposing Institution: Commercial organization

Themes
Theme 1: Sun-Earth Connection
Theme 2:
Theme 3:
Theme 4:

Foreign Participation: Yes

Our UK partners at RAL and MSSL will provide the CCD Camera Systems including the CCDs, which they will obtain from Marconi. They will also be scientific participants.

Type of Hardware: Single Instrument

Type of Investigation: Instrument on SDO Spacecraft

Proposal Summary/Abstract

The Atmospheric Imaging Assembly (AIA) investigation being proposed by Dr. A. M. Title of the Lockheed Martin Advanced Technology Center will provide, for the first time, simultaneous high-resolution images of the entire visible inner corona, thus allowing us to quantitatively understand the large-scale fields, currents, and plasma atmospheres of the corona. A resolution of 1.2" over the entire disk, a cadence below 10 s, and extensive thermal coverage is obtained with a set of normal incident EUV telescopes. A guide telescope is included for use in stabilizing the EUV images and to provide fine-guider pointing signals to the spacecraft. The investigation includes an active EPO program that builds upon the existing programs for SXT, SOHO/MDI, TRACE, and Solar-B that will be coordinated with the SDO/LWS programs. It also includes preparations for joint analysis of AIA data with the data from the other instruments on SDO as well as other observatories in space and on the ground. The AIA team contains experts in all of the disciplines required to carry out the complete investigation.

Certification of Compliance with Applicable Executive Orders and U.S. Code
By signing and submitting the proposal identified in this Cover Sheet/Proposal Summary, the Authorizing Official of the proposing institution, as identified above (or the individual proposer if there is no proposing institution): **1. certifies that the statements made in this proposal are true and complete to the best of his/her knowledge;** **2. agrees to accept the obligations to comply with NASA award terms and conditions if an award is made as a result of this proposal;** **3. provides certification to the following that are reproduced in their entirety in this NRA: (i) Certification Regarding Debarment, Suspension, and Other Responsibility Matters; (ii) Certification Regarding Lobbying, and (iii) Certification of Compliance with the NASA Regulations Pursuant to Nondiscrimination in Federally Assisted Programs.**

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EXECUTIVE SUMMARY

The Atmospheric Imaging Assembly (AIA) will provide, for the first time, multiple simultaneous, high-resolution images of the corona over a wide range of temperatures. The 1.2 arcsec resolution, 46 arcmin field of view (Fig. C-1), 10 s cadence, and 10^4–10^7 K temperature span provide comprehensive access to the geometry of the coronal field, and allow the unambiguous separation of the spatial evolution of the field from thermal and density changes in the coronal atmospheres.

AIA provides an advance in information rate by a factor of >1,000 over TRACE. Four of our eight wavelength bands open new perspectives on the solar corona, having been imaged only during rocket flights. These major advances are required for progress in understanding coronal dynamics, and promise far-reaching discoveries in the basic physics of solar processes, as well as in the forecasting of solar activity and its geo-effectiveness.

By combining AIA data with Helioseismic and Magnetic Imager (HMI) magnetograms, White-light Coronagraphic Imager (WCI) images, and available spectroscopic data (such as from the Atmospheric Imaging Spectrograph (AIS) and Solar-B EIS), we will gain new insights into the corona's evolving 3-D magnetic connections, including field emergence and retraction, and the coupling to the heliosphere. We will probe the conditions necessary for reconnection to occur, and explore the effects of coronal currents. By comparing AIA observations with models, we will estimate the input of electromagnetic energy into the large-scale corona, and its ultimate release as thermal, bulk kinetic, and radiative energy.

The global view and 10 s cadence allow discovery of the causal relationship between relatively slow magnetic field evolution and energy storage, and the rapid energy releases in flares and coronal mass ejections (CMEs). Another rich area of discovery that will be greatly enhanced by AIA is coronal seismology. In addition, the broad thermal coverage of the corona that is provided by AIA will aid the interpretation of short-term irradiance variations observed with SDO's irradiance spectrometer SIE.

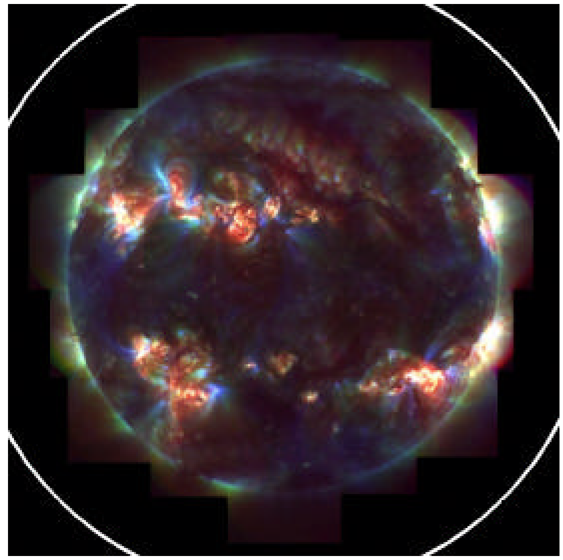

Fig. C-1. *AIA observes in 4 (E)UV channels simultaneously, alternating to cover up to 10 channels, imaging a 46 arcmin area (vignetted to 41 arcmin at the detector edges) with 0.6 arcsec pixels. It will provide the first panoramic view of the dynamic corona at all temperatures at a ~10 s cadence; TRACE needed ~2400 s for this 3-channel mosaic (171Å, 195 Å, 284 Å).*

Data will be accessible to all via the Web typically within minutes of receipt. Easy-to-use publicly-available software for data access and analysis (to be embedded in the SolarSoft IDL libraries) will make AIA data accessible to the broad International Living With a Star (ILWS) user community. A movie browser will enable easy and rapid inspection of the unprecedented data stream, including data from other relevant instruments. These features are expected to significantly enhance the science return.

AIA will make an immediate contribution to space weather forecasting through an event catalog that is updated by autonomous software as data are received. This on-line event catalog will be augmented by visual inspection of the data within 12-24 hours. Filament and sigmoid developments, flares, field emergence, and other events requested by interested parties will be elements of the up-to-date catalog that allows easy selection and retrieval of data on multiple similar events for further detailed study.

AIA has four 20-cm, dual-channel telescopes. The thermal coverage of six narrow-band coronal EUV channels (Table C-1) in successively higher ionization states of iron allows us to detect and trace a variety of structures throughout their evolution including flare temperatures above 4 MK. He II 304Å and UV images span the atmosphere from temperature minimum to transition region, and allow alignment with other instruments. Pre-launch calibrations and in-flight comparison with other instruments will make AIA the best calibrated EUV imager ever flown.

The baseline observing model alternates between two passbands in each of the four telescopes, with a total cadence of 10 s, with exposures short enough to avoid image smearing by velocities up to 150 km/s (the sound speed of the active-region corona). There will be an optional mode based on partial CCD readouts for selected channels at a 2 s cadence to yield sharp images of ejecta and waves moving as fast as 900 km/s. These short exposure times are achieved using high-quantum efficiency detectors and high reflectance optics.

Our international team brings extensive heritage from Yohkoh, SOHO, TRACE, Solar-B, and STEREO, including experts in normal incidence optics, detector systems, image stabilization, instrument control, high-volume telemetry, and data archiving and access. The team includes investigators of Solar-B, STEREO, GOES, TRACE, SOHO, and IMAGE as well as the ground-based SOLIS and the new Swedish solar telescope; this ensures the coordination needed to follow events from Sun to Earth.

Our observational and theoretical expertise not only extends from the solar interior to the corona, but also includes heliospheric, geomagnetic, and ionospheric physics, irradiance modeling, and stellar activity. Co-Investigators are responsible for coordination of broad research themes with other research efforts, in particular other ILWS investigations.

Real time, continuous AIA data will be uniquely appealing to a broad audience. Our E/PO program, building on multi-mission experience, includes intern programs, curriculum development, teacher training, and direct access to museums and science centers. The university partners will train students as future ILWS scientists.

Lockheed Martin continues to be committed to a strong, internally-funded program to develop data access and viewing tools, including both hardware and (publicly available) software.

Considerable cost savings are identified that can be achieved by a systems approach to both the scientific and technical aspects of the investigation, in particular by sharing hardware, software, and data archives between AIA, Stanford's HMI, and Southwest Research Institute’s AIS.

We also propose a guide telescope for SDO that is essentially a copy of those on TRACE and STEREO.

Table C-1. *AIA wavelength bands*

Channel	D1††	Ion(s)	Region of Atmosphere*	Char. log(*T*)
Visible	-	Continuum	Photosphere	3.7
1700Å	-	Continuum	Temperature minimum, photosphere	3.7
304Å†	12.7	He II	Chromosphere, transition region	4.7
1600Å†	-	C IV+cont.	Transition region + upper photosphere	5.0
171Å†	4.7	Fe IX	Quiet corona, upper transition region	5.8
193Å†	6.0	Fe XII, XXIV	Corona and hot flare plasma	6.1, 7.3
211Å†	7.0	Fe XIV	Active-region corona	6.3
335Å†	16.5	Fe XVI	Active-region corona	6.4
94Å†	0.9	Fe XVIII	Flaring regions (partial readout possible)	6.8
133Å†	4.4	Fe XX, XXIII	Flaring regions (partial readout possible)	7.0, 7.2

*Absorption allows imaging of chromospheric material within the corona; † in baseline observing program; ††FWHM, in Å SDO-0005

C1 SCIENCE INVESTIGATION

C1.1 Goals and Objectives

The primary goal of SDO is to understand solar variations that influence life and society. It achieves that goal by targeted basic research focused on determining how and why the Sun varies, and on improving our understanding of how the Sun drives global change and space weather (Fig. FO1-1). To this end, the AIA focuses on the evolution of the magnetic field in the Sun's atmosphere, and its interaction with embedded and surrounding plasma.

Yohkoh, SOHO/EIT, and TRACE images of the corona are dissimilar at distinct temperatures, even if the temperature difference is rather small [1, Fig. C-2]. In addition, these missions have shown that all coronal structures evolve in density, temperature, and position on time scales as short as minutes. Waves, non-uniform flows, and impulsive phenomena occur on significantly shorter time scales. Currents embedded in the field may build up over weeks or longer, while release of those stresses may take only a fraction of a minute. *Yohkoh and SOHO have shown, moreover, that there are no purely local field topologies: the short and long-term evolution of the corona is affected by both nearby and distant magnetic sources.*

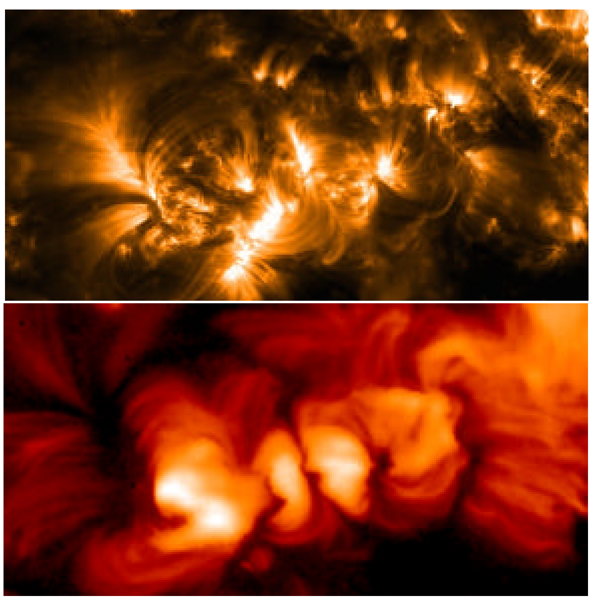

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Fig. C-2. *The coronal appearance depends strongly on the temperature at which it is viewed; narrow thermal bands, together spanning a broad temperature range, as offered by AIA, are needed to observe as much of the magnetic geometry as possible. The upper panel shows the 1 MK corona as observed with the TRACE 171 Å passband (700´350 Mm); the lower panel shows the 2-5 MK corona simultaneously observed with Yohkoh/SXT.*

To understand these properties of the Sun's dynamic magnetic field and the coronal response to it, SDO must record both the surface magnetic field, using the H(V)MI, and image the corona completely and accurately in space, time, and temperature. To achieve this, *the AIA investigation provides the following essential capabilities* (see foldouts):

1. A view of the entire corona at the best feasible resolution compatible with SDO's constraints, providing coverage of the full thermal range of the flaring and non-flaring corona, at a thermal resolution limited only by atomic physics in order to have minimal line-of-sight confusion,
2. A signal-to-noise (S/N) ratio for standard exposures that reaches 100 in optimal conditions, with a dynamic range of up to 10,000, and
3. Essentially uninterrupted viewing for at least months at a time at a temporal resolution of ~10 s, and preferably faster during energetic transient phenomena.

These capabilities are met by our design:

1. Four 20-cm, dual-channel normal incidence telescopes, that observe a 41-46 arcmin field of view in up to ten (E)UV channels, with 0.6 arcsec pixels
2. Detectors with a full well of 150,000 electrons (e^-), with typically 15 e^-/photon, a readout noise of 12 e^-, and data compression that is nearly lossless,
3. A standard baseline observing program running most of the time, while observing from SDO's geo-synchronous orbit.

With these capabilities, AIA will reveal, for the first time, the changing topology of the magnetic field even as the coronal plasma is changing in temperature, including flare plasma hotter than a few million Kelvin. It images each area on the Sun 10× faster per wavelength than TRACE at twice the number of coronal channels, with a 20-fold increase in the number of imaged pixels, and no telemetry limitations. Compared with the full-disk SOHO/EIT, AIA runs at 700× their usual image frequency, with 16× more pixels per image, in typically 8 instead of 4 channels (Fig. FO1-2). The AIA thus represents an increase in the information rate for coronal observations by a factor of 1,000 to 22,000.

C1.1.1 AIA Research Themes

Five broad research themes structure our science investigation and address the overarching questions formulated in the SDO Science Definition Team report (Table FO1-1):

1. Energy input, storage, and release: the 3-D dynamic coronal structure.
2. Coronal heating and irradiance: thermal structure and emission.
3. Transients: sources of radiation and energetic particles.
4. Connections to geospace: material and magnetic field output of the Sun.
5. Coronal seismology: a new diagnostic to access coronal physics.

Energy Input, Storage and Release

To determine where magnetic free energy resides in the corona, we will compare the coronal observations with potential-field models. To quantify the free energy, we must apply detailed non-potential and magnetohydrodynamic (MHD) models.

The large-scale coronal field is controlled by widely distributed sources. In order to establish the resulting field geometry, the AIA is designed to image the entire low corona (Table C1-1, Figs. C-2 and FO1-3). In combination with H(V)MI magnetograms and WCI coronagraph images, these observations provide the information needed to improve our understanding of coronal dynamics.

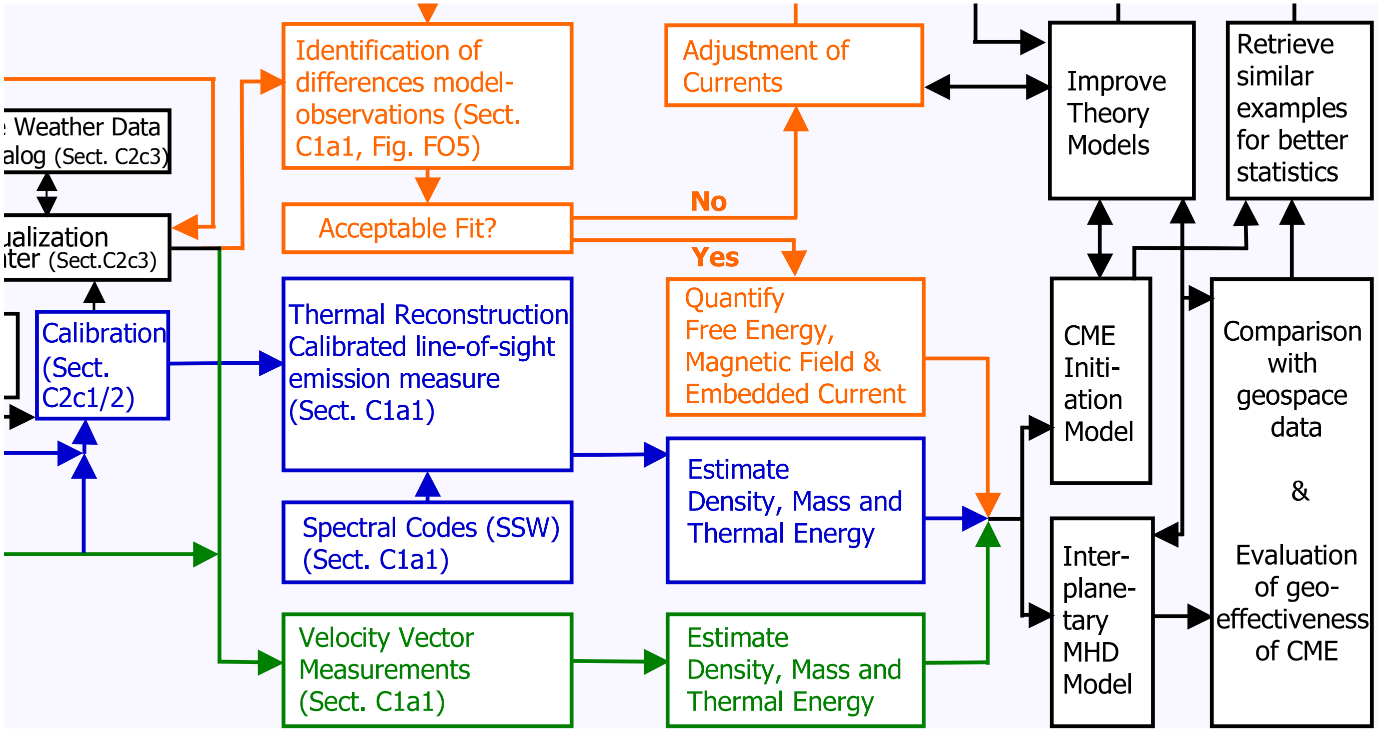
Likely sites of major eruptions are indicated by sigmoids, filaments, field emergence into pre-existing active regions, and field cancellation regions. Such configurations carry helicity, contain currents, and are consequently strongly non-potential. We will locate configurations with considerable non-potential energy within the coronal field by detailed comparison of models with observations.

To obtain a complete view and understanding of the structure and dynamics of the coronal magnetic field, the AIA observations must be compared with models.

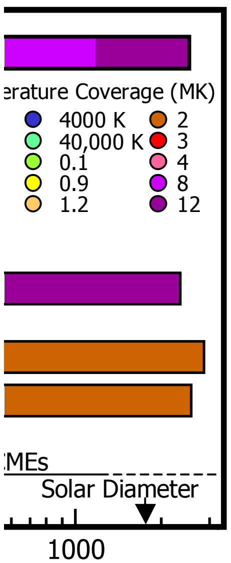
A potential field model, with a heliospheric source surface [2], will serve as a first element in the field extrapolation (Figs. FO1-1, FO1-5) to establish where significant current systems exist in the corona.

Non-potential modeling in part relies on vector field information that will come from SDO's vector magnetograph, if selected, or—at reduced spatio-temporal coverage—from other observatories, including Solar-B's Solar Optical Telescope, the Advanced Stokes Polarimeter of the High-Altitude Observatory, SOLIS of the National Solar Observatory, and the new Swedish telescope on La Palma. A complicating factor is that the non-force-free nature of the photospheric and lower chromospheric field causes significant effects in the coronal field [3]. The Hα images of Solar-B and SOLIS, and the SOLIS chromospheric magnetograms, will provide additional information to help us understand the transition of field from photosphere to corona through the non-force-free lower atmosphere.

Our team will develop and evaluate several approaches to determine the current systems responsible for the observed coronal structure in non-potential situations. A semi-empirical generalization towards non-potential fields will be made by volume transformations of the field to match observed structures [4]. Parallel research will develop more general (non-linear) force-free extrapolations and comprehensive MHD models. Co-Is in Europe [5] and in the U.S. [3, 4, 6, 7] are dedicated to



Requirement / Science theme		Spatia
		Field of Vie Δx= 1Mm
1) Energy Input Storage & Release *Dynamic Coronal Structure*	A D B E C F G	Full Corona 40′-46′
2) Coronal Heating & Irradiance *Thermal Structure & Emission*	D B C G	Active Regions
3) Transients *Sources of Radiation & Energetic Particles*	D B E C G	Majority of Disk
4) Connections to Geospace *Material & Magnetic Field Output of the Sun*	D E F G	Full Disk +off-limb
5) Coronal Seismology *Access to new physics*	D C	Active Regions



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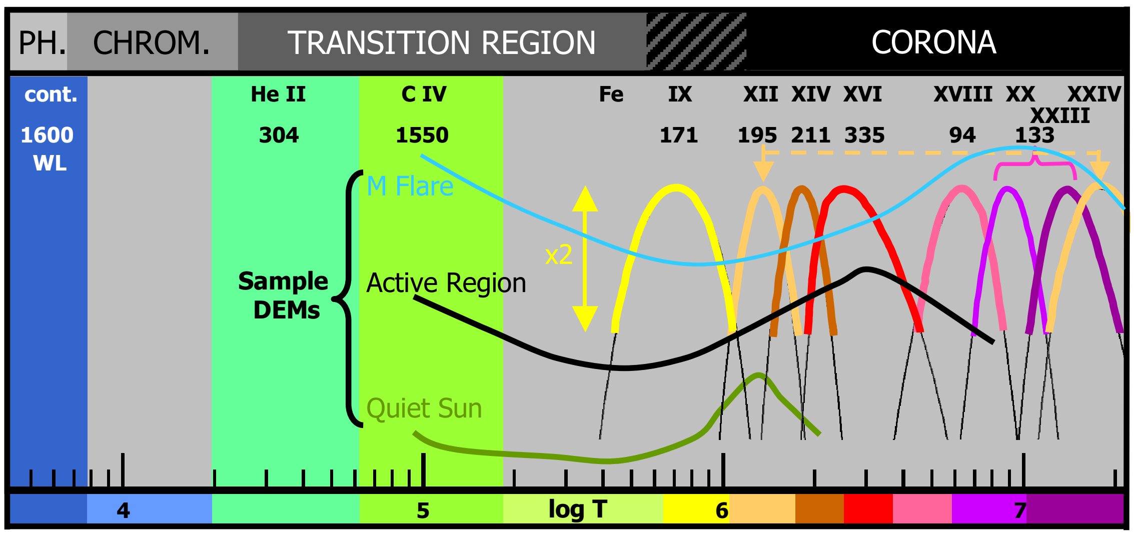
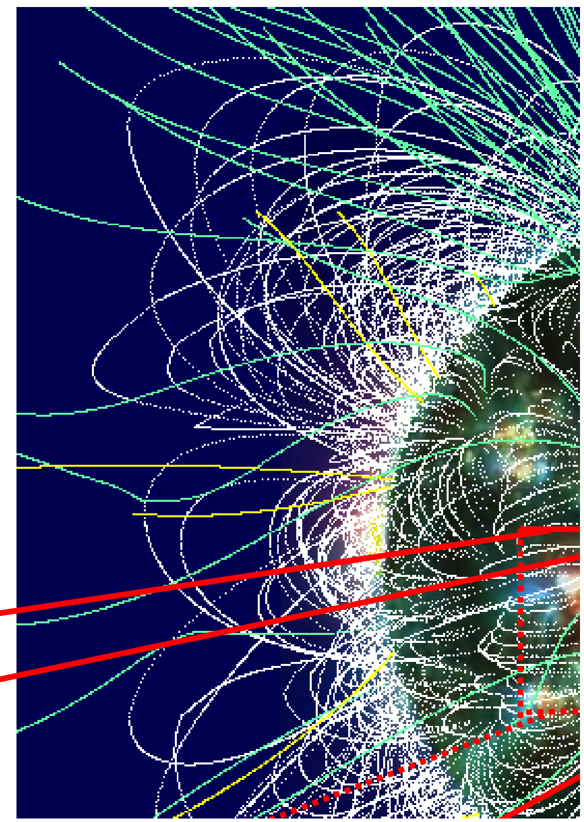
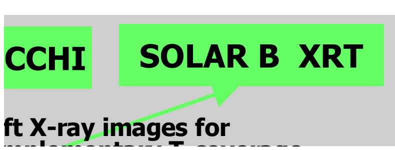
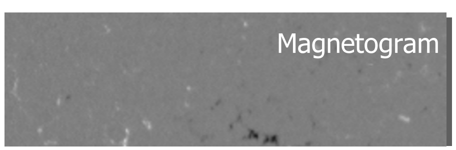
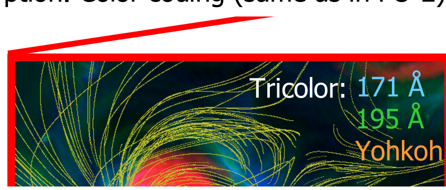


Fig. FO-3: AIA thermal coverage and resolution ranges from photo-sphere to corona. For coronal lines we show normalized ionization fractions; these lines also image chromospheric material in the corona in absorption. Color coding (same as in FO-2) shows temperature coverage & resolution.









optimizing their models for the AIA investigation. Visualization tools will be employed to compare model and observation (including evolving versions of Fig. FO1-5a).

Another approach that we will utilize is that of 3-D field reconstructions. One method useful for relatively slow changes is dynamic stereoscopy [8], which relies on solar rotation to provide different perspectives. Another is the use of true stereoscopic data from the STEREO mission. Additional field information is derived by correlation tracking of irregularities in flows observed with AIA combined with spectroscopic line-of-sight measurements made with SDO's AIS, if selected, or—at lower cadence—Solar-B/EIS. If enough such measurements of vector velocities can be made along structures within the time scale on which the field evolves, we can establish the 3-D geometry independent of other measurements.

Coronal field strengths can also be measured by combining coronal images with microwave images at different wavelengths [9, 10, 11], obtained with the Very Large Array, the Owens Valley Solar Array, and the future Frequency Agile Solar Radiotelescope. This method of measuring the coronal magnetic field employs well-calibrated, multi-thermal EUV images to derive the spatially resolved differential emission measure (DEM), an essential quantity to calculate the bremsstrahlung contribution to the radio emission, and ultimately exploit the dependence of the radio emission on the magnetic field to determine the field strength. The AIA images are ideal for this task, and promise significant advances in this area of research.

Understanding the dynamics of the coronal magnetic field is key to forecasting solar activity and space weather.

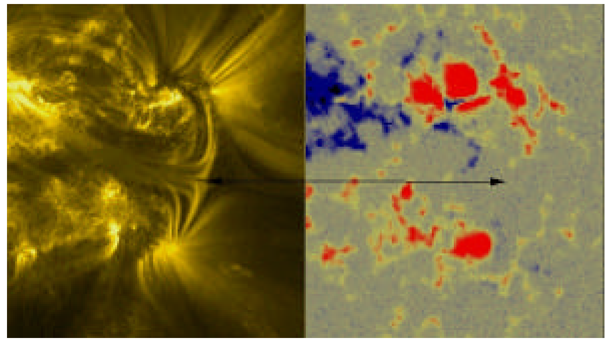


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Fig. C-3. *AIA will image the coronal field configuration, including X points such as that shown on left, observed with TRACE; HMI observations will provide the magnetogram information, as in the MDI magnetogram on the right. Loops change in temperature as they move through the X point, which causes TRACE to lose track of them. The multi-channel AIA will not suffer from that problem.*

The dynamics of the coronal field depends on the time needed for currents to reconfigure and fields to reconnect. Observations have already revealed that connections between distant active regions form within hours of emergence of new magnetic flux; this process is even faster when field emerges within an active region. Reconnection appears to be especially efficient at coronal null points (Fig. C-3).

An example of reconnection in the high corona was discovered by Yohkoh/SXT in flows among cusped structures above post-eruption arcades, interpreted as reconnected magnetic fields downstream of large-scale current sheets [48, 49]. Their extent is ~10 – 30 Mm, with a temperature above 10 MK, and downward velocities that may exceed 500 km/s. The two high-temperature channels of AIA will image these structures and the outflows at unprecedented resolution, and may shed light on the patchiness of reconnection in the sheet, suggested by the strong intermittency of hard X-ray and radio emission [50, 51]. Moreover, AIA will have an excellent opportunity to observe any related inflows into such regions that may occur at much lower temperatures [52].

At present, studies of reconnection are hampered by the continual thermal evolution of plasma. This causes structures to fade from a band pass in typically minutes to tens of minutes in quiescent states [1] and much faster in transients. The wide thermal coverage by AIA will distinguish between correlated thermal evolution of adjacent loops and true geometric evolution of the magnetic field. Combining that with AIA's large field of view and dynamic range, we will be able to map a much larger fraction of the field than is possible now.

Quantitative empirical constraints including topological change, speed of field lines, intermittency of the processes, and amounts of dissipated energy will help test the various reconnection theories [12].

The disappearance of magnetic field from the corona forms an integral part of the study of coronal field dynamics. The retraction of flux (and its helicity) with a preferential orientation may be essential for a Babcock-Leighton type dynamo [13]; its study is thus important in answering the question why the Sun varies. Expulsion of field and helicity from the Sun affects the heliospheric field [14], but after decades of study, observational limitations still keep us from determining how much flux retracts in an active region relative to what disperses away, and how much of the dispersing flux is eventually expelled into the heliosphere [15, 16]. While Solar-B will study field evolution on active-region scales, the combination of AIA and HMI is uniquely suited for the study of flux disappearance from the entire Sun by allowing us to track the field's 3-D evolution in detail.

Forecasting of solar transients requires understanding of the evolution of the coronal field towards unstable configurations by stresses induced at the solar surface.

Continuous photospheric (vector) magnetograms (from H(V)MI, SOLIS, or - for part of the disk - Solar-B) in combination with AIA imaging will enable us to map the magnetic shear and magnetic neutral lines over the full disk at H(V)MI's 1 min cadence, and to estimate the work applied to the coronal field and the injection of field into the corona. Field models (previously described) can then be compared with these observations to study the rate at which magnetic free energy is injected and removed; these comparisons will be even more valuable if chromospheric vector magnetograms are available [17].

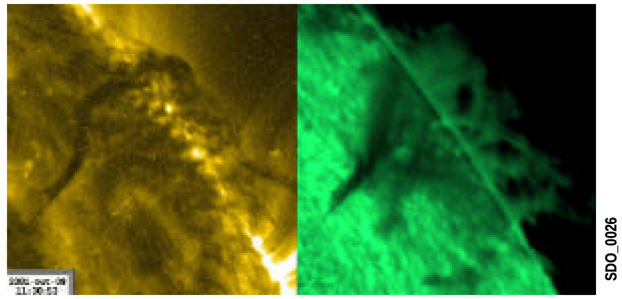

Fig. C-4. AIA offers views of filaments both in absorption (coronal EUV) and emission (He 304Å), complemented by Solar-B and ground-based observations. This example shows a polar-crown filament as seen in the TRACE 171Å channel (left) and in Hα at Big Bear.

The twists and linkages of the coronal magnetic field, measured by the (self and mutual) magnetic helicity, present important aspects of this study. Helicity (often measured relative to a potential field) is a globally conserved quantity that can be redistributed through the coronal field during reconnections. This property of helicity, in principle, allows us to better understand and forecast how changes in one field configuration are associated with sometimes distant other changes that together conserve total relative helicity. Magnetic helicity is injected into the corona mainly by emerging flux, but also by shearing flows [18, 19]. It then somehow cascades to large scales to form magnetic structures like sigmoids [20] and filaments. Helicity is ultimately removed by flux retraction, CMEs, filament eruptions, or cancelled during reconnection of opposite helicity regions. Helicity studies require the continuous, full-Sun observation of the evolving coronal field linkage at the spatio-temporal resolution offered by AIA, in combination with the HMI measurements of the flux of magnetic helicity and energy through the photosphere.

Large-scale helicity evolution will be studied by observing quiet-Sun and intra-region filaments in absorption in the EUV (Fig. C-4) as well as in the He II 304Å channel, and sigmoids in the hotter (335Å and 94Å) coronal channels. We expect that the large field of view and high cadence of AIA will reveal field geometries like those of filaments but that are not filled with chromospheric material. This expectation is based on TRACE data that provide tantalizing glimpses of such fields by fleeting brightenings that move so fast that their motion is generally blurred; AIA observations will be much better suited to studying these phenomena because of the high-cadence and broad thermal coverage.

Coronal Heating and Irradiance

To understand the origin of changes in coronal radiation, we must characterize the corona's evolving thermal structure with adequate spatial-temporal resolution.

AIA will identify sources of variation in the full-Sun spectra observed by SDO's SIE and by the XUV Photometer System (XPS), on the SORCE satellite of the NASA Earth Science Enterprise. AIA's wavelength set allows accurate determination of the amount of material at all coronal temperatures from about 0.7 MK up to 20 MK, i.e., it allows the determination of the DEM (Fig. C-5, [21]). To achieve this goal, the temperature spacing for the AIA pass bands is made as close to the interval over which specific ions contribute as atomic physics and technologically feasible passbands allow. The 10 s cadence is essential to following the evolution of flare plasma.

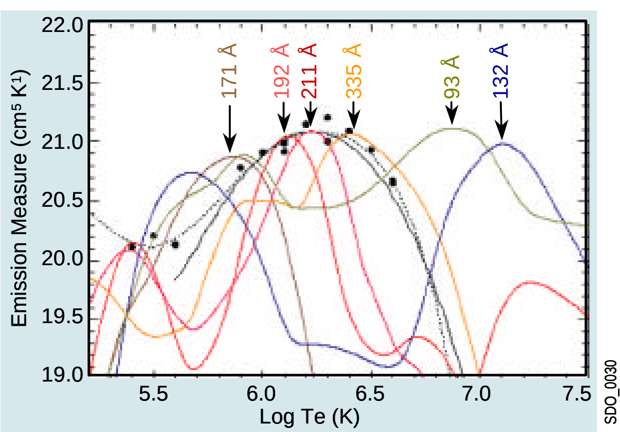

Fig. C-5. *The temperature coverage of the AIA allows DEM reconstructions for a wide variety of features, demonstrating the complete view of the evolving plasma. Dots show the net DEM derived from 12 small SOHO/CDS rasters and 4 Yohkoh/SXT filter images. The black curve is the recovered DEM based on simulated AIA data. The responses of the individual coronal AIA channels are shown normalized to the DEM where each product of response and DEM peaks.*

We selected only coronal iron lines to minimize potential problems with abundance variations [22] in the derivation of the thermal structure. To compute the complete spectrum emitted from each pixel, the chemical composition needs to be established [23, 24] from observations by SDO's SIE and, if included, UIS, or Solar-B's EIS.

The lower-temperature channels are also important for irradiance studies: the broad band UV channel is a proxy for chromospheric variability, while the He II 304Å line, as the strongest emission line below 1200Å, is crucial for the study of irradiance variations driven by the transition region.

Irradiance modeling places strict constraints on instrument calibration. We will measure CCD efficiency, multilayer reflectance, and filter transmissions and perform an end-to-end calibration of the instrument prior to launch. SIE observations will enable in-flight relative calibration of the EUV channels. Observations with the Solar-B EIS spectrograph, X-ray telescope (XRT), and with SDO's AIS, will be invaluable for point-by-point relative calibrations, and in-flight assessment of the contributions from different lines to the pass bands. These calibration efforts will make AIA the best calibrated EUV imager ever flown.

One of the SDO goals is to find easily observable proxies that allow forecasting of the Sun's X-ray and EUV irradiance. The AIA investigation provides a road to that goal (at least in non-flaring conditions) that relies on field extrapolations combined with modeling of the many loop atmospheres embedded within that field. The latter requires knowledge of the properties of coronal heating. In fact, comparison of such modeling for the global corona with spectroscopic data for the Sun as a star constrains how heating depends on field parameters, as was demonstrated in a recent, first study of this type [25]. Intermediate steps towards understanding solar soft X-ray and EUV irradiance include the derivation of a point-by-point emission measure distribution for the entire Sun based on comprehensive, calibrated imaging data, such as will be provided by AIA [26].

Comprehensive thermal coverage and calibration of AIA will further the study of coronal heating, a primary enigma in astrophysics.

AIA images will allow accurate determination of the distribution of temperature along loops. In combination with loop modeling, this will provide information on the distribution of heating along loops, on the temporal variability of that heating, and on the dependence of heating on local field or loop system parameters, including a derivation of the total required heat input by comparing the observations to model results. Whereas recent studies based on TRACE data indicate that coronal heating occurs primarily within the lowest 20,000 km of the corona, that conclusion rests on simple filter ratios to constrain temperature [27]. Possible correlated changes in density and temperature create considerable ambiguities. AIA's thermal coverage is essential to fully address this problem.

It remains unclear what role so-called microflaring plays in the overall coronal heating. Studies of the related short-term loop variability require separation of thermal and density variations to constrain the intermittency of heating, as do investigations of the observed frequent deviations from hydrostatic equilibrium [28]. Current instrumentation results in separate intensity distributions for active regions and quiet Sun that are largely disjoint in energy range [29, 30, 31], so it is unclear whether they have the same shape. Moreover, the detailed shapes of these distributions are quite sensitive to corrections for instrumental limitations. As a result, extrapolations of the frequency distributions remain too uncertain to establish the relative importance of small events to the total heating. With a precision limited essentially only by photon noise, the AIA will measure flares at smaller energies than ever before and trace thermal variations with unprecedented accuracy.

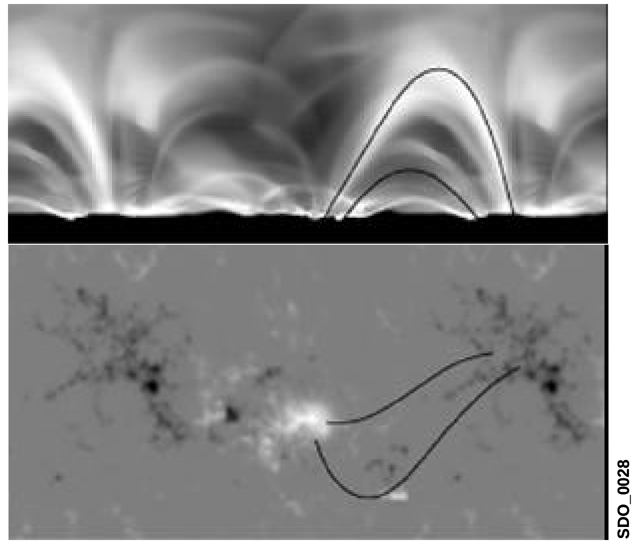

Fig. C-6. *AIA observations will be compared with coronal simulations based on HMI magnetograms, as in this simulation. A simulated 171Å image, as seen in projection, is computed with a full 3-D MHD simulation of coronal field dynamics and heating for an observed magnetogram (bottom; used as periodic boundary condition). A pair of sample field lines is shown. Computations by B. Gudiksen and Co-I Å. Nordlund.*

The AIA images will be compared with MHD computations of coronal heating, that are even now approaching the fidelity required for detailed loop-to-loop comparisons [32, 33, 34, Fig. C-6]. The observations will thus enable us to deduce which coronal heating mechanisms are most consistent with observations. Moreover, AIA observations will be compared with Solar-B and SOLIS observations of the low chromosphere and AIS observations of the high chromosphere and transition region to elucidate the puzzling lack of correlation between chromospheric and transition-region brightness patterns on small scales [35].

Transients

Flares, CMEs, filament destabilizations, sprays, and other transients are sources of radiation and energetic particles, and therefore prime drivers of violent "solar weather". Transients result from the sudden conversion of magnetic energy into bulk, thermal, and non-thermal energy as magnetic field reconnects. Theories of 3-D reconnection [39, 12] involved in such transients are still in their infancy, and advances in its understanding are hampered by observational limitations.

AIA is designed to make a leap forward in understanding transient initiation and evolution. Its high-cadence, full-disk, multi-temperature observations up to ~20 MK will reveal the reorganizing field in the initial phases of flares and of filament eruptions, as well as the later evolution as the field relaxes into its new state. Four pass bands (94, 133, 211, and 335Å) will observe the evolution of the coronal plasma for the first time at arcsec resolution for temperatures between 3 and 15 MK at high cadence, opening entirely new domains of the corona to detailed study. When AIA is operated in its fast mode with partial readouts, the ~2 s cadence for bright, flaring regions will for the first time image the initial phases of transients at a range of temperatures essentially simultaneously and at high spatio-temporal resolution. The well-calibrated AIA observations also allow us to determine the time dependent energy release, from impulsive flares to sustained long-duration events [40, 41].

Prior to SDO's launch, we expect major advances in our understanding of high-energy properties of flares from RHESSI; AIA will add to that by the study of lower temperatures, possibly even in conjunction with RHESSI.

The UV-visible channel provides information on magnetic connections to flare sites during the impulsive phase: particle beams that travel along the field reveal the endpoints of these connections wherever they impact the chromosphere [42]. The temporal resolution and thermal coverage of AIA allows accurate measurement of time differences between coronal and lower atmospheric brightenings, and thus help distinguish high-speed particle beams from slower thermal conduction. Mapping the conjugate endpoints of particle propagation pathways will allow further tests of 3-D models of the coronal and heliospheric field.

As observation and theory have advanced over the last decade, the distinction between the different types of transient phenomena has blurred [36, 37, 38]: the evolution of the large-scale surrounding field appears to be intimately coupled to rapid field destabilization. It remains to be explored whether this is a global response to a perturbation, or whether a global change triggers the instability. The decade of Yohkoh observations shows that field rearrangements during CMEs and flares often involve more than a quarter of the solar disk.

The details of the evolution of the field involved in CMEs remain elusive. One aspect is the energy budget of the field: the relatively high energy state of the opened field needs to be countered by a lowering of energy elsewhere, possibly far away. For example, a CME may involve field from several arcades, most of which is not opened [44, the “breakout model”]; in some cases these associated flux systems even involve trans-equatorial loop systems [45]. Furthermore, we need to understand the distinction between the common constrained filament eruption and the less frequent fully-developed CME. We also need to understand how, and how much, flux escapes from the Sun during CMEs [46, 47]. Adding to these problems is the fact that the CME field often is not force free [43]. AIA's field of view and thermal coverage enable observation of much more of the field involved in the early phases of CMEs than is possible now with SOHO and TRACE. Moreover, the high cadence of AIA allows us to observe exactly how the field evolves from one state to another, which is important to assess helicity evolution and where and how much field is not force free.

The exposure duration of order 2.7 s and the 10 s cadence of the AIA channels allow observations of velocities up to 150 km/s in quiescent conditions, or up to 900 km/s in bright features, without motion blurring. The standard cadence of about 10 s, and the higher cadence of partial images for the high temperature channels, will enable us to see the changes in connectivity as the field evolves. We will also observe high-speed flows, jets, (shock) waves, and plasmoids induced by the reorganizing field, even those so fast that they lead to some image blurring. TRACE has revealed the ubiquity of such propagating irregularities, but the improved cadence, coverage, and exposure durations of the AIA will allow us to study these phenomena in detail.

Connections to Geospace

The connections between the Sun and geospace are a cornerstone of the ILWS program. To understand how the Sun's variability affects life and society, we must understand how the products of this variability are transported into and through the heliosphere, and how they interact with the Earth's environment. The AIA investigation will make substantial quantitative advances in many areas relevant to this problem. At the foundation of this expectation lies the improved understanding of the global coronal field and its extension into the heliosphere. We've described this for the pathways of energetic particles into the heliosphere, the irradiance, and the triggering of flares and CMEs.

The dynamic coupling of the closed corona to the heliospheric field can be observed using the sensitive AIA telescopes.

On the scale of supergranulation, the network field is replaced every few days in a continual process of emergence in ephemeral regions and flux cancellation due to collisions between opposite polarities [53]. This process that occurs on small scales forces reconnections that drive a reorganization of the magnetic field on all scales. TRACE observations of the corona above quiet-Sun regions hint at a multitude of dynamic structures, particularly in exposures of minutes or more [1]. The sensitivity of the AIA will allow us to observe these structures with much shorter exposure times, and hopefully reveal how this field couples to that in the heliosphere, particularly in the open-field configurations of coronal holes at the base of the fast solar wind.

The relatively slow and gusty component of the solar wind originates in the evolving transitions between the Sun's closed field and the open field that reaches into the heliosphere; this occurs wherever gradients in field strength and plasma pressure effectively compete. This transition may be involved in the puzzling whirling motions that are observed in off-limb active-region data of SOHO/CDS and TRACE [1, 54]. The high-frequency, high S/N, multi-temperature images obtained with AIA will break the critical empirical barrier that now hampers observation of this phenomenon, and the evaluation of its role in the solar wind's origin and acceleration.

The combination of H(V)MI, AIA, and WCI observations with modeling efforts will deepen our understanding of the interface between corona and heliosphere.

Currently, the standard approach to modeling the heliospheric field is to combine a source-surface potential-field model and Parker spiral. This method involves various hard-to-validate, pragmatic corrections [55, 56, 57], and ignores wind stream interactions. Detailed observations of the field geometry, in particular in the first few tenths of the solar radius above the limb where most of the separation of open and closed field occurs, will help us understand these corrections, and the role currents and field dynamics play (Fig. FO1-1). This will improve the fast but simple source-surface modeling and guide the more advanced MHD modeling.

One key tool in this is a surface dispersal model (already developed by our team, [58]), that simulates the evolution of photospheric field near the limb where it is hard to observe, and on the backside of the Sun. Combined with H(V)MI magnetograms of the visible hemisphere, and seismological proxies for flux on the backside of the Sun (with assigned polarities) this provides a good approximation of the entire surface field needed as a basis for global coronal modeling.

AIA and WCI data, combined with such models, will allow the study of coronal holes as parts of the heliospheric field. Team members with expertise in MHD modeling and field geometry studies will address this coupling. Such modeling will be exercised and refined starting with the Solar-B and STEREO missions. Its full potential is met when full-disk SDO data enable us to cover scales from active regions to the entire corona.

The high-cadence AIA images enable study of CMEs and associated (shock, blast, and other) waves that are launched into the heliosphere. CME-related shock waves [45, 59] likely play a significant role in the generation of solar energetic particles from within the heliosphere [60]. Furthermore, the calibrated AIA images, enable us to estimate the mass involved in an ejection because they cover a wide range of temperatures, (Fig. FO1-1; as already applied to SXT, EIT and TRACE observations, [45, 61]), and—for prominence eruptions—provide the acceleration profile of CME-related structures to be compared with WCI data higher up. Combination with WCI data will allow us to estimate velocities and field-strength evolution in the initial phase of CMEs, both important to the severity of related geo-magnetic storms [62]. The AIA images will also elucidate whether the short-term coronal dimming during CMEs [63] is a consequence of a change in density (related to field evolution) or temperature (reflecting expansion or modified heating) or both.

An exciting prospect is offered by combining AIA images with spectroscopic measurements from the fast-rastering, large field of view AIS on SDO or the EIS on Solar-B: together, these measurements provide the vector velocity that enables an accurate forecast of the geo-effectiveness of a CME even before it is visible in a coronagraph. Clearly, the coverage of chromospheric, transition-region and coronal diagnostics by the SwRI AIS are best suited for this. AIA, WCI, spectrographic, and hopefully STEREO observations can also be combined to estimate 3-D velocity vectors if spectroscopic data are not available.

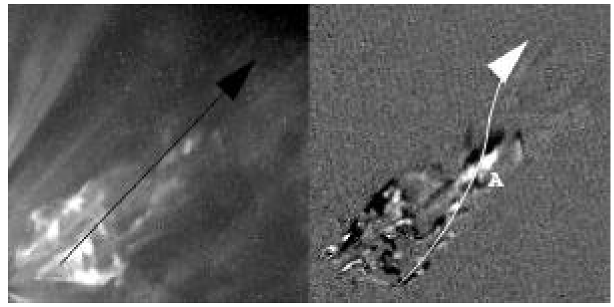

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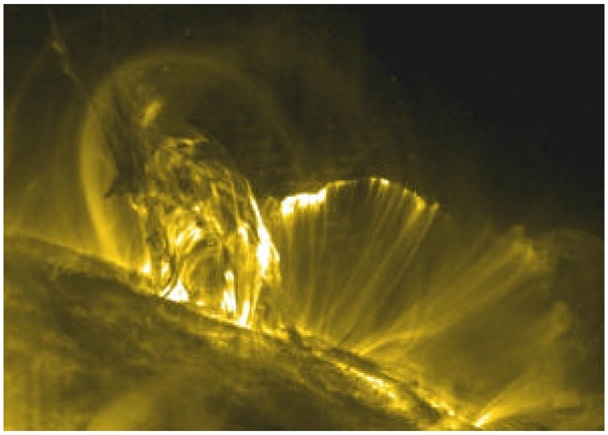
Fig. C-7. *The 10 s cadence and ~2.7 s exposures of the AIA allows imaging of field evolution during eruptive events, such as this observed with TRACE in its 171Å pass band, with unusually short 12 s exposures, reading out the CCD 2´2 summed to obtain sufficient signal. The ejection (left) along the arrow had a projected speed of ~400 km/s. The field twisted in the process: bright blobs moved along curved tracks in difference images (right). At the usual 30-40 s cadence of TRACE this twisting motion would have been missed altogether.*

Observations of the initial evolution of the field in a CME (including any unwinding of the helical field, Figs. C-7 and C-8) will help modelers compute the further evolution through the heliosphere (including CME-wind and CME-CME interactions). Of particular importance here is the direction of the field that will be at the compressed front of the magnetic cloud, and the field orientation throughout its interior; these quantities determine the magnitude of a geomagnetic storm and the auroral currents [64].

Another important aspect is that SOHO's LASCO frequently observes matter falling back to the Sun, even from eruptions that reach beyond 6 solar radii [65]. What determines how much of the CME mass falls back? What does that mean for its geo-effectiveness? We will study these processes by combining data on erupting filaments seen in emission in He II 304Å, in absorption in the EUV channels, and in scattered light by the WCI.

The AIA archive and software system are based on and developed from our experiences using SOHO and TRACE data.

The easy to use AIA data, catalogs, software, and archives are designed to make an immediate contribution to space weather studies.



SDO 0031

Fig. C-8. *The initial evolution of the tangled field that is part of a filament destabilization (and often a CME) can be studied with AIA through continuum absorption, as seen in this TRACE 171Å image, and also in emission in the He 304Å channel. The high-cadence, full-Sun and full-thermal coverage of AIA will provide comprehensive views of these events, and allow measurements of velocities and column depths and of the evolution of the magnetic field.*

In addition, the AIA investigation will develop and maintain an event catalog that is updated as data are received. Rapid brightenings, early rises of CME filaments, and other activity diagnostics will be listed on the web within minutes. All images will be inspected visually within 24 h in order to (a) augment the catalog with filament and sigmoid developments, flare properties, flux emergence sites, wave phenomena, and other products requested by interested parties, and (b) create experience in researchers that stimulates the exploration of new avenues and discovery of new phenomena in traditional solar physics areas as well as in the wider ILWS context. To achieve this, the AIA team will explore how to best include heliospheric and geospace data in the daily assessment of events.

Coronal Seismology

Coronal seismology is a promising new field of solar physics opened by TRACE and SOHO. Examples of seismic responses of the corona have been found in large-scale coronal Moreton and EIT waves [66] and in polar plumes, sunspot fields, and what appear to be ordinary loops. Most striking are the transverse oscillations seen by TRACE in association with ~8% of all C, M, and X-class flares observed [67, 68]. Oscillating loops always appear to be near a large-scale magnetic separator; the reason remains a mystery. Transverse oscillations have recently also been observed spectroscopically in hot (10^7 K), off-disk loops observed by SUMER [69].

Many transverse oscillations are (nearly) resonant modes. Coronal seismology based on such modes offers the possibility of measuring the mean Alfvén speed along loops. This requires the measurement of the period and the loop length (from 3-D field reconstructions). The measured Alfvén speeds can be tested against estimates based on other methods, such as field extrapolations and density estimates from brightness data or spectroscopy. Such independent consistency tests make these measurements very valuable.

The high cadence and short exposure times of AIA not only will show many more cases of coronal field oscillations, but promise to also uncover other types of MHD waves.

These waves can be used, via dispersion relation to deduce basic properties of the coronal plasma such as its field strength and dissipation characteristics that are key to any modeling effort, but are hard to measure otherwise. Note that the 171Å and 193Å channels are so sensitive (see Table C-2) that they allow access to frequencies as low as 0.25 Hz using a dedicated 2 s exposure cycle with partial readouts.

Coronal oscillations decay unexpectedly rapidly. This fact is subject to conflicting interpretations: it may be that coronal dissipation is 10^9 times higher than classically expected [70]; footpoint leakage of wave energy into the chromosphere may be much more efficient than expected from classical 1-D chromospheric models [71]; or wave energy may radiate away through running waves [72]. Discovering how these processes damp the oscillations by studying a large number of events at high cadence and S/N will deepen our understanding of the Sun's atmosphere by quantitatively establishing properties such as viscosity, resistivity, and wave propagation.

The AIA design allows us to exploit the potential of coronal seismology, further enhanced by spectroscopic measurements of densities and line-of-sight velocities, for example by the SDO/AIS and the Solar-B/EIS.

C1.1.2 Roles of the science team

The success of the SDO mission and of the broader ILWS program depends on a systems approach to understand solar variability and its effects on the Sun-Earth system.

The scientific capabilities of SDO and of the ILWS program will be greatly enhanced by coordination with the international fleet of solar and geospace spacecraft, and ground-based observatories. This will enable extensive coverage of Sun, heliosphere, and geospace. PIs or Co-Is from many of these instruments are on the AIA team, as identified in Fig. FO1-4 (and Appendix G1); they are committed to making optimal use of this intimate linkage to achieve the ILWS goals.

The implementation plan for the five research themes (§C1.1.1), and the broad investigator base, maximize the AIA scientific return, and optimize our support of the broader program through both operational and scientific coordination. The coordinators for these research themes are: *(1) Energy input, storage, and release*, T. Metcalf and C. Schrijver; *(2) Coronal heating and irradiance*, H. Warren and P. Martens; *(3) Transients*, L. Golub and N. Nitta; *(4) Connections to geospace*, S. Fuselier and Z. Mikic; *(5) Coronal seismology*, B. De Pontieu and E. DeLuca. The coordinators are responsible for optimal use of AIA resources by coordinating with (1) our other research themes and with other ILWS investigations (such as those in the Targeted Research and Technology program), (2) non-ILWS investigations (including efforts in MHD field modeling, the NSF SHINE and RISE programs, and the DoD solar MURI program), and (3) other observatory and modeling groups. Impetus and focus will be maintained by science team meetings and sessions at appropriate general meetings. The communication with the solar physics and broader ILWS communities are the responsibility of the PI, Science Lead, and the theme coordinators.

Our team members and colleagues in their groups have extensive observational and theoretical expertise in all fields from the solar interior to the Earth's ionosphere. The AIA research will benefit from this existing multidisciplinary expertise, from coordination with other projects that these investigators are involved in, and from the added value of European research at no cost to NASA.

The AIA team will closely collaborate with other teams in order to maximize scientific return. These include the Solar-B XRT and EIS investigations, and with the AIS proposed by SwRI, if selected, for supplementary imaging, spectroscopic, and cross-calibration data. L. Culhane, L. Golub, D. Hassler, and T. Tarbell (*coordinator*) are responsible for these efforts. (Vector-)Field data will come from Solar-B/SOT (A. Title, P.I.; *coordinator)* and H(V)MI (P. Scherrer; *coordinator*). Ground-based NSO/SOLIS is committed to supporting the AIA science investigation by providing coordinated observations of the vector field, Hα, and the chromospheric magnetic field (C. Keller; *coordinator*). Coordination with the New Swedish Telescope on La Palma (G. Scharmer; *coordinator*) increases the coverage by its very different longitude. B. Fleck will coordinate our research with ESA and the European science community.

If the Stanford HMI or SwRI AIS are selected, substantial cost savings can be achieved for instrument development, data management, analysis software, and data distribution and archiving (§F5 and Cost Table B-4). Research areas to be coordinated for AIA and HMI include measurements of flow fields and magnetic displacements, flux emergence and retraction studies, and seismic coupling of photosphere and atmosphere during transients.

C2. Science Implementation

The AIA instrument provides spectacular TRACE-like spatial resolution (1.2 arcsec), SOHO/EIT-like full disk coverage (>41 arcmin), with excellent temperature coverage (6000 K to 20 MK) and temporal cadence (2 to 10 s).

The AIA makes use of extensive hardware and software heritage from the Yohkoh/SXT, SOHO/MDI, TRACE, GOES/SXI-N, STEREO/-SECCHI (LMSAL is responsible for the EUVI), and Solar-B (FFP and XRT) satellite programs, ensuring achievable schedule and budget performance while maintaining reliability. Integral to AIA is a guide telescope that is based on the successful TRACE and SECCHI designs. The AIA represents a major advance over TRACE by providing a 1,000-fold increase in data acquired, observing the entire solar disk simultaneously with different temperature lines, while utilizing an efficient, low-noise CCD detector.

C2.a AIA Instrument Overview

The science objectives (see §C1.1) require:

1) Seven EUV and three UV-visible channels
2) >41 arcmin FOV with 0.6 arcsec pixels
3) A detector full well >150,000 electrons and camera readout noise of ≤12 electrons
4) A continual 10-s cadence
5) A capability to adjust the observing program for solar conditions or to implement specific scientific objectives, including a 2 second cadence for flare studies.

We meet the optical requirements with an array of four dual-channel telescopes (Fig. FO2-3) mounted together with a guide telescope that provides signals for both control of the AIA active mirrors and for fine pointing the spacecraft. Back-illuminated thinned 4096×4096 pixel Marconi CCD detectors provide the required spatial resolution, field of view and full well. To obtain the 10-s cadence a complete camera readout is accomplished in 2.3 s while maintaining ≤12 electron readout noise. The camera has the ability to sum on chip and to select subregions to obtain 1 s readouts, allowing a 2 s cadence. A RAD750 computer manages the image and housekeeping data streams and controls the observing sequence through tables that are uploaded from the ground. Image statistics generated on-board can be used for automatic exposure control and experiment mode selection. The wavelength channel is selected by filterwheels in three of the telescopes combined with an aperture selector in the fourth.

C2.a.1 Optical System

Optical Design. The AIA telescopes are identical Ritchey-Chrétiens with apertures sufficiently large for the required 10 s observing cadence in all channels. The low secondary mirror magnification (2.945) allows a spatial resolution of 1.2 arcsec (0.6 arcsec pixels) to be maintained across the field of view (FOV), and provides a high degree of alignment robustness. Predicted image spot sizes compared to a 1.2 arcsec square box are shown in Fig. C-9. Nominally optimized for a 41-arcmin-diameter circle, the FOV extends to 46 arcmin along the CCD diagonals (Fig. C-1). The geo-synchronous SDO orbit exposes the AIA to substantial fluxes of energetic electrons. The telescopes are therefore fully baffled to shield the CCD from electrons, minimizing charged particle noise in the images.

Mirrors. The mirrors are fabricated using state-of-the art computer-controlled figuring methods. The required surface finish (3 Å microroughness, 4Å mid-frequency [79]) is achieved by proven superpolishing methods. The primary mirrors are light-weighted by 50-60% to reduce mass. Two vendors, with demonstrated capability—Tinsley (now SSG) and Goodrich—have responded to our RFE.

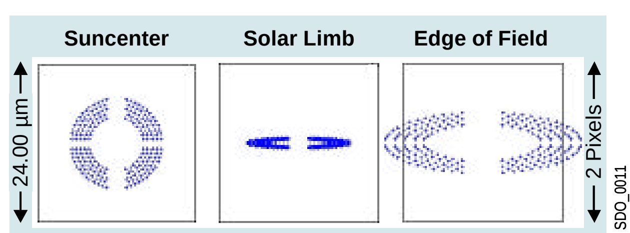


Fig. C-9. AIA spot diagrams at a focus setting optimized for a large range of field angles.

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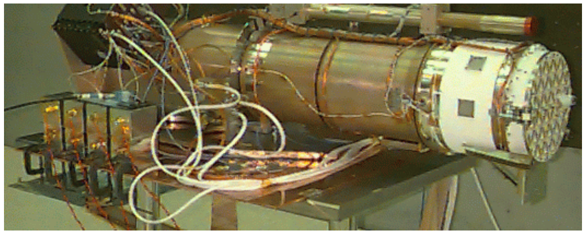


Fig. FO2-1. *TRACE instrument with guide telescope*

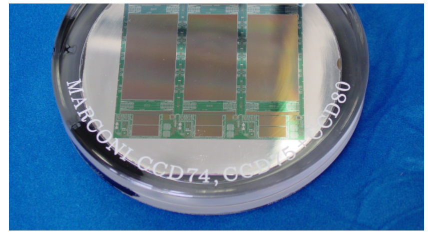
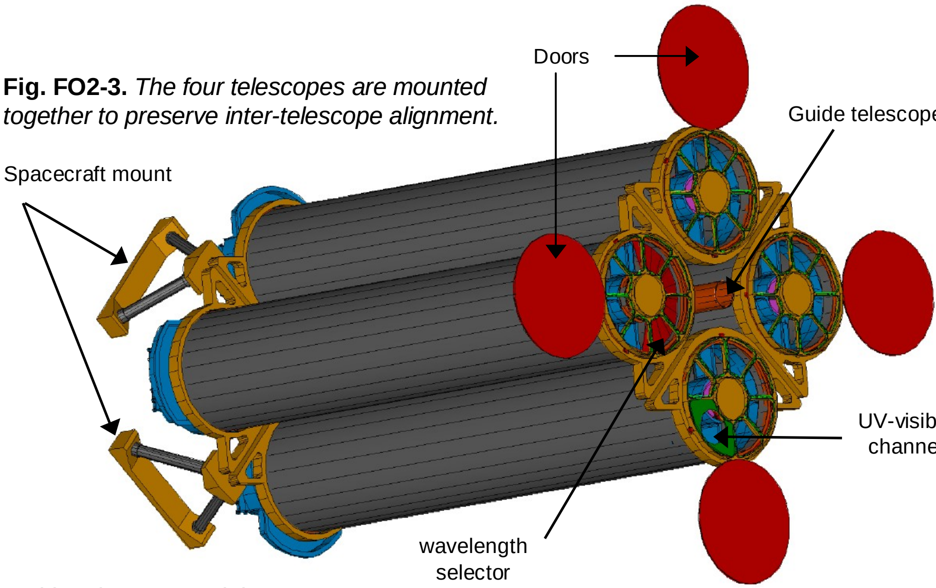


Fig. FO2-2. *The AIA 4K×4K CCD is based on the FPP 2K×4K waver design.*

1	1600	C IV/continuum	80%	Al	Bandpass	Bandp
	1700	Continuum	80%	Al	on	Bandpass
	4500	Continuum	80%	Al	MgF_2	Bandpass
	171	Fe IX	50%	Mo/Si	Al, 1500Å	A
2	94	Fe XVIII	40%	Ru/Y	Zr, 2000Å	Zr
	304	He II	18%	SiC/Si	Al, 1500Å	A
3	133	Fe XX/XXIII	68%	Mo/Si	Zr, 2000Å	Zr
	335	Fe XVI	17%	SiC/Si	Al, 1500Å	A
4	211	Fe XIV	42%	Mo/Si	Al, 1500Å	A
	193	Fe XII/XXIV	48%	Mo/Si	Al, 1500Å	A

*3000Å Zr on 4000Å Polyimide can be used as a neutral density filter du

Fig. FO2-3. *The four telescopes are mounted together to preserve inter-telescope alignment.*



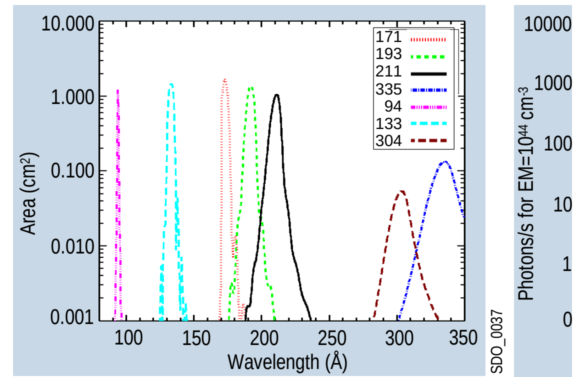


Fig. FO2-4. *Effective area of each wavelength channel*

rical block diagram including the guide telescope and the it boards in each function is indicated by shadowed boxes.

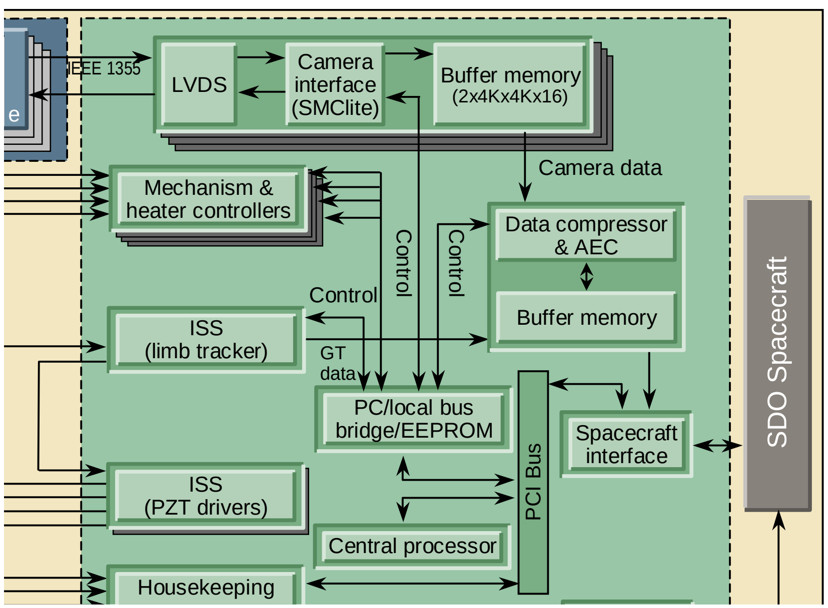
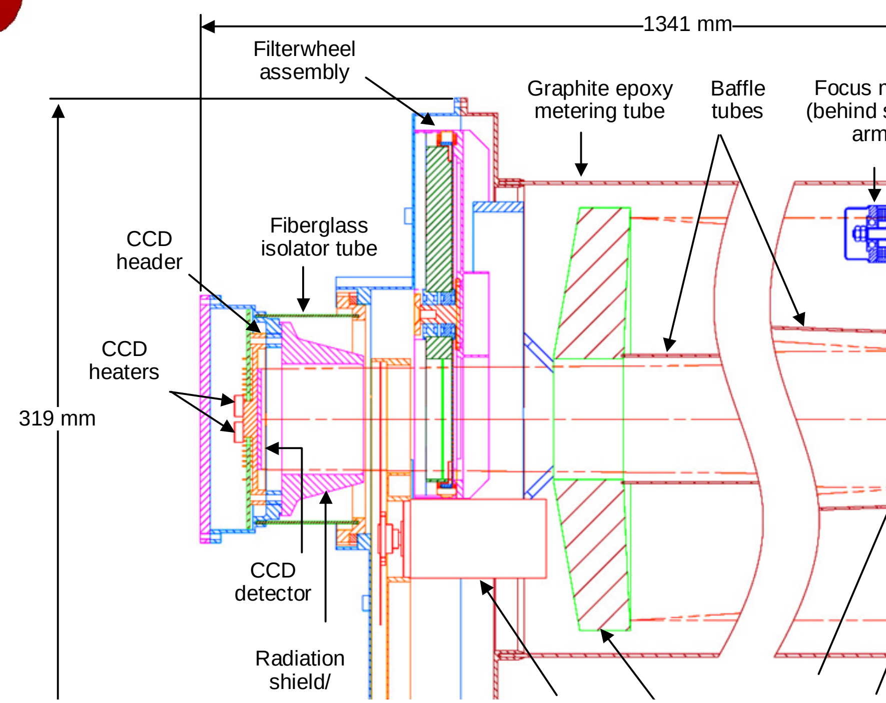


Fig. FO2-7. *The cross-section of a single AIA teles*



EUV Multilayer Coatings. Normal incidence thin film coatings determine the set of EUV wavelengths. They are similar to coatings used in MSSTA, NIXT, EIT, TXI, and TRACE [73, 74, 75].

To meet AIA science objectives the EUV coating selection took into account the temperature bands we wish to observe, the exposure times in each band, the coating feasibility, and the optimal distribution of UV and EUV channels among the four telescopes. The line selection is given in Table FO2-2. Multilayer coatings have been produced at all of the chosen wavelengths, and the performance parameters listed are conservative. We have teamed with Drs. Troy Barbee (LLNL) and David Windt (Columbia University) to develop the AIA multilayer coatings.

The areas of the multilayer coatings in the three telescopes without an aperture selector are optimized for the expected counting rates. The 94 Å, 171 Å, and 335 Å channels occupy three-fourths of the telescope aperture and the 133 Å, 304 Å, and UV channels one-fourth.

The Stanford University MSSTA rocket experiment, which is scheduled to fly in April 2002, includes many of the AIA wavelengths in its complement. Some, such as Fe XVIII (94 Å) and Fe XX/XXIII (133 Å) have not been imaged to date. The MSSTA PI, Dr. Dennis Martinez-Galarce, will join the LMSAL group in June 2002 and is committed to working with our team to include MSSTA flight results in the AIA Phase A planning.

Entrance and Focal Plane Filters. The entrance filters and focal plane filters perform three functions: reduce solar heat flux; reject visible light from the focal plane; and discriminate between wavelength regions. In the EUV these functions are achieved with thin film foils. The UV through near-IR light rejection at the CCD camera must be better than 10^{-11}. As was done on TRACE, this goal is met by a rejection of 10^{-5} for the entrance filters and 10^{-6} for the focal plane filters.

Aluminum (Al) and zirconium (Zr) films are used in the entrance and focal plane filters. Luxel Corp has developed Zr films under a SBIR grant. Three telescopes have no aperture selector mechanism. Because Zr strongly absorbs above 250 Å, and Al strongly absorbs below 170 Å, wavelength selection with a crosstalk <0.1% can be achieved by the filter-wheel filters plus the corresponding, Zr, Al, or $MgFl_2$ entrance filter.

The filter wheels have five positions to accommodate a second thin-film filter for all EUV channels and an open position for calibration. The second filters are thicker for added safety and for 133 Å it acts as a neutral density filter during flares. Luxel Corp provides the thin metal filters.

We have determined that the filters do not have to be launched in vacuum, based on our experience with SXT, TRACE, XRT and SECCHI, if their diameter is kept below about 60 mm. The focal plane filters will be protected from acoustic loads during launch by retracting them from the open position of the filterwheel into the filterwheel housing. The entrance filters are substantially smaller than the filters flown on TRACE, and by further subdividing the aperture into eighths rather than quadrants, a door over the aperture is sufficient protection during launch. Similarly sized entrance filters developed for SECCHI have recently passed acoustic and vibration testing without a vacuum chamber.

Effective Areas & Instrument Sensitivity. The instrument sensitivity is high due to highly reflective multilayer coatings and excellent CCD quantum efficiency, enabling imaging with good photon statistics within the required 10 s cadence. The effective areas (including CCD effective quantum efficiency) of the EUV channels are shown in Fig. FO2-4. Shown in Fig. FO2-5 is the response of the AIA to a wide range of solar plasma temperatures obtained by multiplying these curves with predicted solar spectra obtained using the

Table C-2. *AIA photon count rates per pixel for 2.7s exposures.*

Channel	Quiet Sun	Active Region	M-Class Flare	Microflare* DEM=2´10^28cm^-5
171	290	5,800	22,000	8,900 (@T= 0.9 MK)
193	87	5,700	300,000	5,400 (@T= 1.4 MK)
211		3,200	11,000	2,400 (@T= 2.0 MK)
335		800	19,000	330 (@T= 3.0 MK)
94			44,000	100 (@T= 6.0 MK)
133			880,000	570 (@T=13.0 MK)
304	†31	†520	22,000	
1600	§1500	§5000	1,000,000	

Notes:
* Microflare temperatures set to peak temperature response of given wavelength channel
† Derived from SOHO-EIT observations.
§ For 1.0 s exposures. Derived from TRACE data. SDO-0038

CHIANTI code. Predicted photon count rates for a typical active region, and for an M-class flare are given in Table C-2. The relevant count rates for an exposure time of 2.7 s are at or above 100 photons/pixel, thus allowing a photometric accuracy of 10% or better. AIA will also detect microflares or transient brightenings such as observed by Yohkoh, which have a typical column EM of $2{\times}10^{28}$ cm^{-5} [76].

UV-visible Channel. The UV-visible channel of AIA is a simplified version of the TRACE system that has operated in space for 4 years now with very little if any optical degradation. These simplifications occur because AIA does not have the TRACE requirements for 1216 Å imaging. The most valuable TRACE UV channel has proven to be at 1600 Å, where a 200 Å-wide transmission band includes the C IV lines (10^5 K), various chromospheric lines, and the UV continuum formed in the temperature minimum. High throughput allows short exposures and high cadence, while the presence of C IV provides sensitivity to transient energy releases. In order to unambiguously identify footpoint locations during flares, a second UV channel (TRACE "1700 Å") is included that shows the temperature minimum and low chromosphere but very little plasma at transition region temperatures.

The UV-visible channel front window is MgF_2 with a coating to reject most visible light (~10^{-5} transmission is sufficient for the visible channel) while passing UV (>20% transmission). The window has a slight power to compensate for the focus shift introduced by the UV focal plane filters. The primary and secondary mirror coatings are Al with a MgF_2 overcoat, which are applied by the EUV coating vendor to eliminate handling by another vendor. The 1600 Å filter, on a MgF_2 substrate, has a 200 Å bandpass, identical to TRACE. The 1700 Å filter is the same design but shifted 100 Å and applied to a fused silica substrate that absorbs all light below 1600 Å, eliminating the C IV lines (10^{-7} transmission). The visible filter provides a 500 Å bandpass centered at 4500 Å and allows routine ground testing and in flight image quality evaluation using phase diversity techniques.

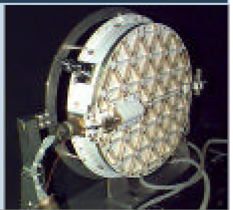
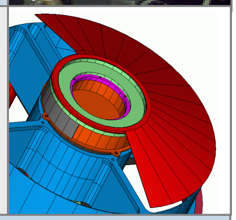
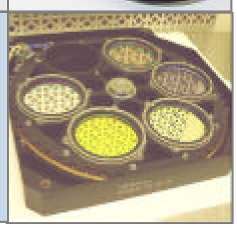
C2.a.2. Mechanisms

The AIA mechanisms build on the extensive successful flight heritage of SXT, MDI, TRACE, SXI-N, EPIC, Solar-B, and SECCHI (Table C-3). The mechanism locations are shown in Fig. FO2-7.

The shutter, filterwheel, and aperture selector mechanisms are based on brushless DC motors that have high (>100%) torque margins over friction and the magnetic detents, with robust bearing designs. All mechanisms are constructed for an operational lifetime at the image capture cadence of 5 s for 10 years. The aperture selector, filterwheel, and shutter will be life tested. Basic design, performance, and life test methodology is described in [77].

Each telescope has a single-use front door assembly with direct heritage to TRACE and XRT. The assembly consists of the door, a spring-loaded hinge, and a latch. The door is a lightweighted aluminum plate machined with a slight bow on the sealing surface. This bow is squeezed and held flat when the door is closed and latched, increasing the preload on a compressed o-ring to improve the door seal. A redundant paraffin linear actuator operates the latch. For added reliability, the latch holds the door closed when retracted and wedges the door open when the wax actuator is activated.

Table C-3. *AIA mechanisms have flight heritage.*

Mechanism, Design & Performance	
Aperture Door. Simplified TRACE design with redundant paraffin actuators & vibration dampening seal **Performance:** Operation time: 70s Single use	
Wavelength Selector. SECCHI hollow-core motor rotates a conical halfshade. **Performance:** Move time: 0.5 s Req'd life: 63M Ops (5s cadence, 10y) Positional accuracy: ±15 arcmin	
Focus Mechanism. TRACE heritage mechanism updated with greater resolution motor & encoder. **Performance:** Range/resolution: ± 90µm / 3µm Req'd life: 100K operations	
Shutter. EPIC/XRT heritage motor with 175.3 mm blade **Performance:** Beam diam. at shutter: 50.8mm Req'd life: 63M Ops (5s cadence, 10y) Minimum exposure: > 5ms Repeatability/uniformity: ±100µs/±0.5 ms	
Filterwheel. 165mm brushless DC motor w/5 openings. Enlarged motor of SXI and EPIC (shown) heritage. **Performance:** Filter aperture diam.: 55mm Max. op time: <0.9 s (2 filter steps) Req'd life: 63M Ops (5s cadence, 10y) Positional accuracy: ±2 arcmin	

SDO_0016

Each telescope has a focus mechanism actuated by a DC torque motor that moves the secondary mirror over a ±90 µm range in 3-µm steps. The focal plane assembly contains a rotating blade shutter and a five-position filterwheel. Both are scaled versions of those flight qualified for EPIC and XRT. Preliminary analysis indicates that angular momentum compensation is not necessary for the AIA mechanisms, nor has it been required for the previous missions.

Only one of the telescopes (containing the 193 Å and 211 Å channels) has a wavelength selector mechanism. It is based on a hollow core motor used in the SECCHI instrument, and thus is a different concept from the TRACE selector mechanism. The TRACE selector, which makes use of a modified shutter motor and controller, has displayed infrequent anomalous behavior. The problem is not mechanical, but is rather that the control algorithm firmware and software were not robust enough to handle small performance changes over the mission lifetime. The AIA hollow-core motor aperture selector is controlled by a filterwheel-like controller with upgraded firmware and software and the TRACE difficulties are avoided. An example of this mechanism is currently undergoing life testing for the FPP program. As is true of all AIA mechanisms, and as is now standard for SXI, FPP, XRT, and SECCHI, the drive electronics incorporate fault monitoring and a single stepping mode is available in case of excessive degradation.

C2.a.3. CCD and Camera Design

AIA contains four identical 4096×4096 pixel CCD detectors. The CCDs are a Marconi Applied Technologies (formerly EEV) design based on the 2048×4096 pixel devices for the FPP (Fig. FO2-2). They feature low-voltage clocking of the serial output register to minimize power dissipation in the clock driver electronics. The CCDs are back thinned and back illuminated with 12 µm pixels, operated non-inverted to ensure good full well capacity (150k to 200k electrons). A larger physical pixel size would result in an even larger full well, but 12 µm is the largest pixel size 4096×4096 device that Marconi can fit on a silicon wafer using their standard process.

The CCDs are radiatively cooled to below –65°C. SXI program measurements show that Marconi's devices achieve 1 nA cm^{-2} dark current performance at –65°C, which results in less than 0.2 electron/s/pixel. The radiation environment of the geosynchronous orbit requires the CCDs be shielded. The baseline shielding is 10 mm of aluminum to keep total ionizing radiation dose to <7 krad over the mission lifetime and minimize the effects of ionizing radiation from high-energy solar events [78].

Marconi has a long history of manufacturing excellent CCD devices for space applications in the XUV, including the sensors for XRT, the SECCHI/EUVI, and the SXI-N instruments. These devices have high and stable quantum efficiency (QE). The QE of the AIA CCD is expected to be very similar to what has been measured with the SXI-N CCD 64 (see Fig. C-10) and is more than an order of magnitude better than the EUV QE of the TRACE Lumogen-coated detector. Mullard Space Science Laboratory (MSSL) is responsible for procuring and characterizing the CCDs.

Rutherford Appleton Laboratory (RAL) is responsible for the camera electronics. The camera design is based on SECCHI but modified to meet the AIA 2.3 s readout requirement. The camera reads at a rate of 2 Mpixels/s through each of four quadrant readout ports. ASIC and surface-mount electronics packaging technologies minimize camera size, mass, and power requirements. A summary of the camera design characteristics is:

1. Independent control of four CCDs.
2. CCD readout at 2Mpixel/s through each of four quadrant readout ports.
3. 14 bit analog to digital conversion.
4. A CCD readout noise of ≤12 electron rms.
5. Programmable CCD video output gain, and programmable video DC offset level.
6. Programmable (multiple) windowed CCD readout and pixel binning options.

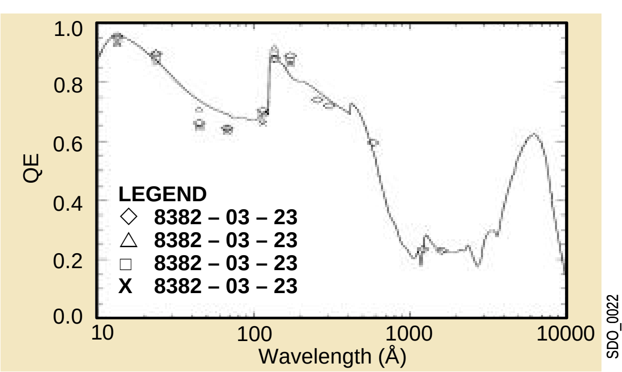


Fig. C-10. *LMSAL measurements of quantum efficiency of four GOES/SXI-N CCD 64 devices. The solid curve is a fitted model.*

RAL has demonstrated that all of these requirements can be met in cameras derived from the SECCHI and EIS designs.

The camera electronics use the same basic waveform generator radiation-hardened ASIC and CCD clock driver circuit topologies as the SECCHI cameras and incorporates dedicated power converters to minimize read noise. Each CCD reads out in parallel through four 14-bit correlated double sampling/ADC video processors whose design is implemented in an ASIC optimized for the 2 Mpixels/s readout rate and the signal gain of the AIA CCD.

Each CCD Driver Card communicates with the instrument computer through an IEEE1355/SpaceWire link, enabling camera programming, camera command, gathering of housekeeping data, and the transmission of digitized CCD video data. Data transmission rate on this link is up to 200 Mbits/s per CCD.

C2.a.4. Structure

Each telescope consists of a 2-mirror Ritchey-Chrétien optical system mounted to a graphite epoxy metering tube that provides alignment and thermal stability.

The primary mirror mounts to the rear tube flange through a system of titanium flexures that ensure the mirror remains precisely aligned, while isolating it from the effect of thermally induced structural changes. Overconstraint is avoided by minimizing rotational stiffness, about all three axes, for each flexure. This mirror mounting approach follows the successful designs used on various ground and space-based telescopes, including XRT, SXI-N, and Chandra.

The secondary mirror assembly is supported on the spider with flexures that locate it radially but permit axial motion for focus adjustments. The focus mechanism is mounted within one of the spider frame arms and has only minimal impact on the available aperture. One telescope has an aperture selector mounted to the front side of the spider.

The primary mirror-mounting ring is the interface to the focal plane assembly, which includes the CCD, shutter, filterwheel, and CCD radiator.

Graphite epoxy mounting structures at the forward and aft ends of the metering tubes mount the telescopes to each other and to the guide telescope and provide the interface to mount the assembly to the spacecraft (see Fig. FO2-3). The telescopes are connected to each other rigidly at the aft end. At the forward end the telescopes are connected together with high spring constant flexures to permit relative axial motion while locking out relative tips or tilts. This arrangement is non-kinematic, but guarantees high stability and is acceptable because the four telescopes are made from identical, ultra-low coefficient of thermal expansion graphite epoxy, and the thermal environment is relatively benign. Preliminary structural analysis indicates that the first mode of the mounted array is above 55 Hz.

No independent instrument pointing system is included because the guide telescope, which is the spacecraft fine pointer, is part of the AIA.

C2.a.5. Guide Telescope

The guide telescope (GT) provides fine-pointing angular measurements that serve two purposes: (1) a signal for the ISS (see §C2.a.6) that suppresses jitter at frequencies well above the spacecraft attitude control system (ACS) bandwidth; and (2) an error signal for the ACS to use for fine-attitude control of the spacecraft.

A solid model and cross section of the GT are shown in Fig C-11. The telescope optical design is identical to TRACE (Fig. FO2-1) without the rotating wedges that were used to point the TRACE spacecraft anywhere on the Sun. It includes an aluminum tube telescope structure, optics, and a Sun sensor. An interference filter at the aperture limits the bandpass of the telescope to eliminate the heat load. The objective lens is a doublet followed by a Barlow lens to achieve the desired focal length within a compact envelope.

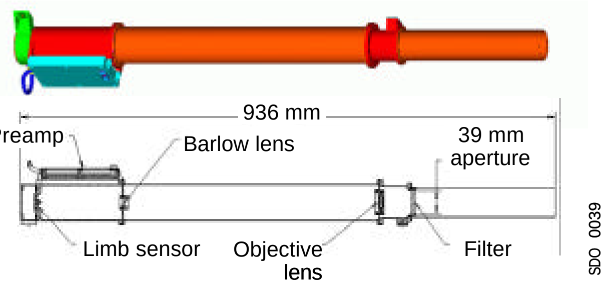


Fig. C-11. *The SDO GT is based on the TRACE and SECCHI designs.*

The lens system images the Sun onto a limb sensor consisting of four bicells (dual redundant photodiodes) positioned at 90-degree locations to detect image motion of the solar limb. A central cone reflects 85% of the light from the solar disk away from the bicells, allowing for greater sensitivity to limb motion. The GT error signal as a function of solar offset angle is shown in Fig. C-12. The sensor is insensitive to solar phenomena. A large sunspot at the limb causes <1 arcsec drift over a period of many hours. A summary of the GT characteristics is given in Table C-4.

The GT meets all the requirements stated in Table 5-2 of the AO, except for the 0.01 arcsec noise equivalent angle (NEA) requirement. While the diode sensors are capable of meeting the AO-specified NEA, the TRACE electronics cannot meet it and the range requirements simultaneously. The GT meets a NEA of 0.1 arcsec, 3σ, which has proven to be more than adequate for the TRACE mission attitude control system. Reducing the NEA at the cost of error signal range will be considered during the Phase A accommodation study if 0.01 arcsec is really required.

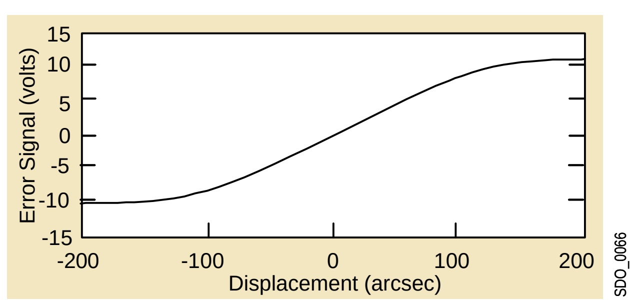


Fig. C-12. *GT error signal as a function of sun offset angle*

Table C-4. *TRACE & SDO GT designs are nearly identical.*

Guide Telescope Physical Properties	
Interference filter bandwidth	λ_0=570 nm; $\Delta\lambda$=50 nm
Optics	Achromat with Barlow
Focal length	1.88 m
Sensor	4 (+ 4 redundant) photodiodes
Linear range	±120 arcsec
Acquisition range	± 24 arcmin
Accuracy	0.1 arcsec
Noise equivalent angle	0.1 arcsec
Bandwidth	>50 Hz
Latency	<0.04 s
Length	936 mm
Mass	2.3 kg (incl. preamp)

SDO_0042

A digital signal interface with the spacecraft is the baseline for SDO, as is done on TRACE and STEREO. The analog signal is digitized to 12 bits and sample averages are passed to the spacecraft on the 1553 bus at a 50 Hz update rate. Additional status bits that indicate which diodes are illuminated and which are saturated, provide information during Sun acquisition. An analog signal can be provided if the spacecraft requires higher bandwidth performance.

C2.a.6 Image Stabilization System

The AIA Image Stabilization System (ISS) is a limb sensor based system that removes sensed jitter by controlling the four active secondary mirrors in each of the telescopes. This system is based on the TRACE ISS.

For the ISS servo control, the GT analog error signals are conditioned and sent to the AIA secondary servos, exactly as on TRACE. The tilt of the secondary mirrors is accomplished with low-voltage PZT actuators with strain gauge displacement encoders integrally mounted. There are four servo loops, one for each AIA telescope, controlled by the GT tip-tilt error signals. Each servo loop is closed around the PZT strain gauges of its active mirror to ensure proper positioning. The servo loops have independent electronic offset and electronic gain control on both the error signals and the strain gauges, allowing the servo loops to be independently calibrated for best performance. Individual servo loop gain control also enables the avoidance of resonances at the full-up satellite configuration. The TRACE system on orbit is very stable, with monthly calibration checks, requiring on-board system updates only twice a year.

The secondary mirror drive electronics are a heritage design, using the same drive circuitry as on TRACE. The total offset range of the mirrors is ±30 arcsec in image space. These mirrors have a first resonance (>500 Hz) much higher than the structural modes of the AIA.

The ISS requires that the analog GT signal is linear in each axis and on-orbit calibration in arcsec/V will be performed at most monthly to ensure proper operation. The image motion measured by the GT must be coherent in amplitude and in phase with the AIA telescopes over the bandwidth that jitter compensation is accomplished. This requires a tight mechanical coupling between the AIA telescope array and GT that is achieved by mounting the GT directly to the telescope assembly. The first resonance of the coupling (55 Hz) is much higher than the required bandwidth of the ISS.

C2.a.7. Electronics

The AIA electronics, shown in the functional block diagram Fig. FO2-6, are built around a BAE RAD750 computer board that was developed by British Aerospace for the JPL X2000 program. This processor is the next generation of the RAD 6000 processor family with which LMSAL has extensive experience on the SXI-N and FPP programs. The AIA electronics are divided into several subsystems described below. The camera electronics were described in §C2.a.3.

The **control computer subsystem** consists of the RAD750 control computer, spacecraft interface, housekeeping data acquisition system, and the PCI bridge. These subsystems communicate over a standard compact PCI bus. The control computer provides a 132MHz RAD750 CPU, 128MB of SDRAM, and 256KB of start-up ROM (SUROM). A Summit type remote terminal interface is made to the spacecraft redundant Mil-std 1553 bus and a LVDS bus interface provides the 58 Mbps science data stream. Housekeeping data (temperatures, voltages, etc.) are formatted as CCSDS packets and provided to the spacecraft over the 1553 bus. The PCI bridge provides a control interface from the PCI bus to the camera interface and buffer, mechanism control electronics, and image stabilization system.

The control computer subsystem includes 4MB of EEPROM that is loaded with flight software at launch. When the AIA instrument power is turned on the SUROM boot loader will load and start the flight software from the EEPROM without further intervention.

The **camera interface and buffer subsystem** contains four fully independent subsystems that can simultaneously acquire camera data from each telescope. Storage memory for two images per telescope is provided so that one image can be passed to the data compressor while another image is being acquired from the camera.

Data compression is performed in hardware using a combination of two schemes, RICE (with a look-up table) and square root binning (SRB). The 58 Mbs telemetry stream requires that AIA data be compressed to 4.3 bits/pixel. TRACE 171A images are 4.5 bits/pixel with a RICE compression scheme. Appropriate SRB (with no loss of significant signal) reduces the 171 Å image to 3.5 bits/pixel. While performing compression, six coefficients for **automatic exposure control** and flag generation are acquired.

The **mechanism control electronics** are essentially identical to those developed for the FPP and SECCHI programs. These designs can be used with little or no modification because the mechanisms also share heritage with these programs. Each AIA telescope has a dedicated mechanism controller board.

The **power subsystems** provide conditioned power to all AIA subsystems and have heritage from the MDI, TRACE, SXI-N, and FPP programs. The AIA power system is broken into two subsystems. One of the power subsystems is located in the CCD camera box and the other is in the main electronics box. Radiation-hardened Interpoint, Lambda, or equivalent converter modules are used. Inrush current limiting and EMI filters needed to meet EMI/EMC specifications are included.

Radiation effects were evaluated using statistical models [78]. Our electronics boxes have 5-mm Al walls, which results in a total dose for a five-year mission of 21 krad. We baseline 100 krad or greater parts and SEU-immune parts are selected wherever possible. The radiation tolerance of the correlated double sampling and analog-to-digital ASIC and FPGAs are enhanced with triple modular redundancy algorithms. The waveform generating ASIC incorporates EDAC memory.

C2.a.8. Software

The flight software is written in C++ and runs on a RAD750 processor using the VxWorks operating system. The VxWorks operating system is used on the SXI-N and Solar B/FPP programs. A minimum of 25% of the AIA flight code is existing code from these programs. The software controls the AIA autonomously with minimum spacecraft and ground interaction.

The software interfaces with the spacecraft over a 1553 bus for the reception of commands and to provide housekeeping engineering data to the spacecraft. It controls the mechanisms, ISS, heaters and cameras. The software commands any combination of exposures from the seven EUV and three UV-visible channels. The software optionally implements automatic exposure control (AEC) using an algorithm that evaluates the six AEC coefficients provided by the compression hardware. No other on-board image processing is performed. A limited amount of on-board fault management is provided to accommodate malfunctions.

There are no time-critical operations for the flight software. The control functions are performed using less than 50% of the CPU capability and memory is sized such that less than 50% is used at launch. A new code image and/or patch code may be uploaded after launch. Code is developed in an incremental approach with additional capabilities being added to support hardware units as they become available for test and integration. Code is maintained using revision control system on the development workstations.

C2.a.9. Thermal Design

The telescope array has active thermal control to maintain the temperature in order to preserve alignment and mirror figure. Primary rejection of solar energy is by the front aperture filters. Radiating surfaces on the telescope sides eliminate the small fraction of energy not rejected by the entrance filters and that generated internally by the mechanisms. Thus, thermal considerations place no limitations on the frequency of mechanism operations. Dedicated radiators passively cool the CCDs. The electronics boxes are thermally decoupled from the telescope assembly and cooled with dedicated radiators.

External surfaces will be covered with MLI with a Ge-black Kapton outer layer to minimize BOL/EOL variation in thermal performance. A redundant set of survival heaters controlled by mechanical thermostats maintains instrument health in the event of emergency conditions.

C2.a.10. Contamination Design and Control

Experience with TRACE, Chandra, SXI, and other solar instruments has shown that successful contamination control begins with instrument design and materials selection. Only very-low outgassing materials that meet ASTM E595 1.00% TML and 0.10% CVCM are selected for use in the telescopes. Materials and components near sensitive optical surfaces are vacuum baked and qualified with QCM measurements to the much lower out-gassing levels that are required to achieve the desired performance. Our design isolates sensitive optical surfaces from sources of contamination. Controlled micro-environments, such as in the optical assemblies and around the filter assemblies, are used to maintain control of the areas with the most stringent cleanliness requirements. A cup-shaped cold getter surrounds the CCD and remains cold when the CCD heater is activated for decontamination.

During instrument assembly the instrument components are cleaned and vacuum baked to meet stringent non-volatile residues (NVR) requirements that are derived from the contamination modeling. The instrument is purged with clean, dry nitrogen during ground operations. Accessible hardware surfaces are periodically cleaned. Environments and inaccessible or fragile surfaces are monitored using optical witness samples, NVR fallout samples, and particle fallout plates. The entrance flight filters are kept in vacuum storage with witness samples until installation shortly before launch to minimize oxidation that would reduce throughput. The focal plane filters are purged in the instrument with dry nitrogen until shortly before launch. This approach was used very successfully with TRACE and is implemented for SECCHI/EUVI.

C2.a.11 Redundancy

Although the AIA is basically a single-string concept, the four-telescope design provides inherent redundancy in the unlikely event of a detector or shutter mechanism failure. The failure of any filterwheel or of the aperture selector would result in the loss of only one EUV channel. The filterwheels contain redundant metal filters in case of pinholes. The GT incorporates redundant photodiode sensors.

C2.a.12. Calibration

The success of the AIA investigation depends on a good calibration of the telescopes. This is performed both at the component and system levels (see Table C-5). Component level cali-

Table C-5. *AIA calibration plan assures that the inter-telescope calibration is ~5%*

AIA Calibration			
Component Calibration	**Quantity**	**Accuracy**	**Facility**
EUV entrance Filters	Transmission	2%	SAO
EUV focal plane filters	Transmission	2%	LMSAL
UV filters	Transmission	3%	Acton Res. Corp
Mirror Coatings	Reflectivity	3%	Columbia Univ. LLNL
CCD	QE	3%	LMSAL
CCD	Spatial resolution	0.1 arcsec	LMSAL
System Calibration	**Quantity**	**Accuracy**	**Facility**
AIA	Effective area	5%	RAL
AIA	Spatial resolution	0.1 arcsec	RAL
AIA	Co-alignment	5 arcsec	

SDO_0061

brations are performed using existing facilities at LMSAL, SAO, the mirror coating suppliers and the UV filter suppliers.

A system-level calibration of the AIA will be performed at Rutherford Appleton Laboratory (RAL) in a facility used to calibrate the SOHO/CDS and the Solar-B/EIS. The AIA is put into a 1m diameter by 3.5m long vacuum chamber that is attached to a source that provides a 5mm diameter beam of collimated radiation containing spectral lines of known intensity. The line intensity is periodically calibrated to the primary standard synchrotron radiation source, the BESSY 2 synchrotron in Berlin. The RAL source is an extremely stable hollow cathode discharge lamp that emits radiation through a pinhole at the focus of a Wolter II telescope to provide a collimated beam. Mapping of each aperture will be performed. The vacuum system is ultra-clean for contamination control and monitored by RGA and QCM instruments and witness mirrors.

The effective area of each telescope will be measured in the RAL facility. Inter-telescope accuracy is expected to be about 5% since the use of the same secondary standard reduces systematic error. The spatial resolution will be characterized to an accuracy of ~0.1 arcsec.

On-orbit cross-calibration with SDO's SIE and the EIS and XRT instruments on Solar-B will provide a check of photometric stability. A blue LED is included in each telescope to monitor CCD flat field and the CCD camera system gain.

C2.a.13. Build, Assembly, and Test flow

The AIA build, assembly, and test flow shown in Fig. C-13 makes optimal use of the capabilities of the AIA team members. Cleanly defined interfaces enable parallel development of the subsystems and efficient integration of the instrument. LMSAL develops the electronics, spider assembly, focal plane assembly, and GT. SAO develops the telescope structure, optics, front door, and telescope assembly mounts, and delivers to LMSAL a complete, tested optical system. RAL develops the camera electronics. MSSL procures and characterizes the CCDs.

Each of the four telescopes is assembled, aligned and tested as a subsystem prior to integration into the telescope assembly. The spider assembly and associated mechanisms are integrated and tested as a subsystem at LMSAL prior to delivery to SAO for integration into the telescopes. Each CCD-shutter-filterwheel assembly is tested and calibrated as a subsystem prior to integration onto the telescope assembly.

The GT is developed and functionally tested before integration with the telescope assembly at SAO. Likewise, the electronics are developed and tested with interface simulators and brassboards prior to integration with the telescope assembly.

The telescope assembly, focal plane subsystems, and electronics are integrated into the AIA instrument at LMSAL. Functional and performance tests are performed using a visible stimulus telescope and the optical alignment of the telescopes and GT is established and verified. The completion of these tasks marks the start of the formal acceptance pro-

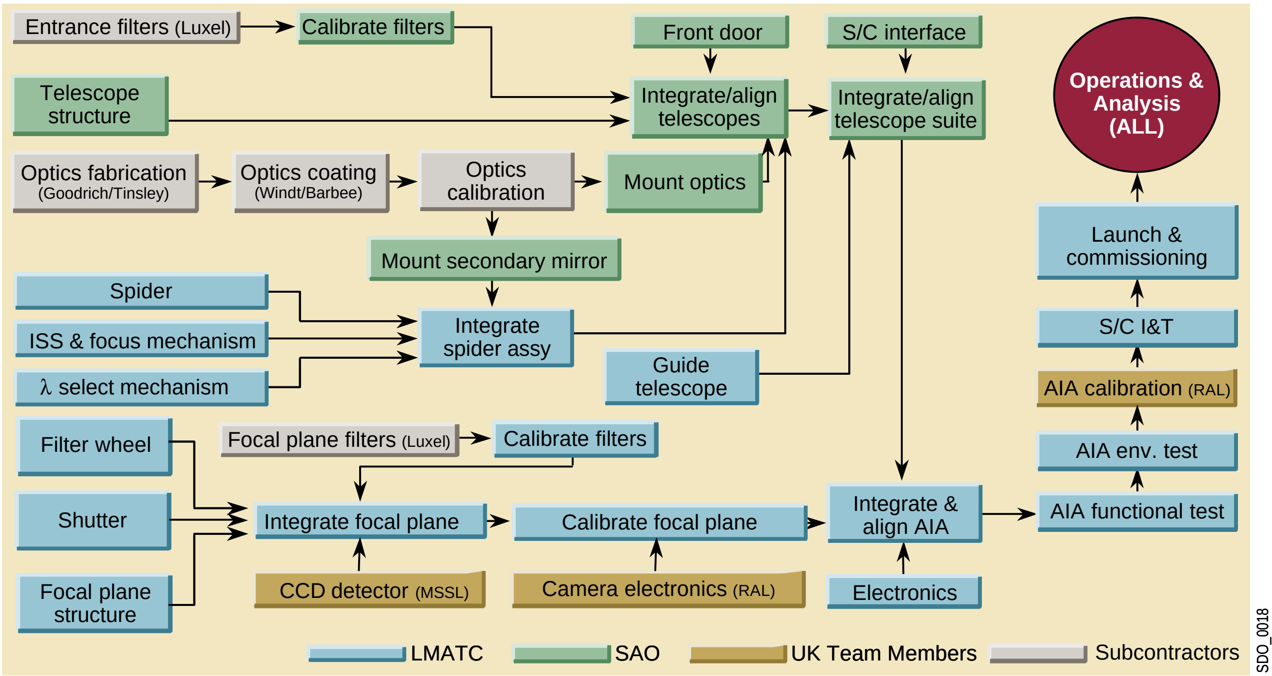


Fig. C-13. *AIA build, assembly, and test flow capitalizes on the capabilities of the consortium facilities and personnel while maintaining clean interfaces.*

gram. A Goddard engineer on the AIA team will support functional tests at LMSAL, will aid in the integration to the spacecraft at Goddard, and will support spacecraft-level testing. Some unique tests of the GT with the spacecraft ACS are performed after instrument integration. A simplified AIA verification matrix is shown in Table C-6.

C2.a.14. Spacecraft Resources and Accommodations

The required spacecraft resources for the AIA mass and volume are shown in Table C-7. The AIA mass (without reserve) of 72.7 kg slightly exceeds the AO nominal allocation of 66 kg. No attempt was made to lightweight components except for the mirror mass estimates. Further light weighting will be explored as necessary during Phase A. Mass reserve is estimated based on the heritage of the individual components. New component designs have mass allocations of 25% and modified designs are allocated 15% margin.

The telescope assembly is mounted on the instrument module. We show a mounting concept in Fig. FO2-3, which likely eliminates mass required for the cruciform structure pictured in the AO. We have therefore considered this mounting structure to be in the spacecraft mass allocation. The electronics box is

Table C-6. *AIA verification matrix.*

Item	Fnc.		Structural, Mech. & Environmental										
	Long Form Functional (CPT)	Short Form Functional (LPT)	Mass, Center of Gravity	Structural Loads (Quasistatic)	Acoustic	Modal Survey	Sine & Random Vibration	Mechanical Shock	Life Testing (Mechanical)	Pressure Profile (Launch)	EMI/EMC/Magnetics	Thermal Balance	Thermal Vacuum
FM AIA (instrument level)	T	T									T	T	T
FM E-boxes	T	T	T	T		T	T	T		A			
FM Tele Assy			T	T	T	T	T	T					
Telescope		T								A			
Door		T					T						T
Spider Group		T											
Aperture selector		T					T		T				T
Focus mech.		T					T		T				
Focal Plane Grp		T											
Filter wheel		T					T		T				T
Shutter mech.		T					T		T				T
Struct Ther Model			T	T	T	T	T	T				T	

FM = Flight Model A = Analysis T = Test
SDO-0020

Table C-7. *AIA & GT mass and temperature allocations.*

Item	Telescope assembly	Guide telescope	Camera electronics	Main electronics	Total (excl. reserve)
Mass (kg)	46.8	2.3	3.8	21.2	**74.1**
Length (cm)	134.1	93.6	19.0	32.0	
Width (cm)	65.0	8.9	15.0	28.2	
Height (cm)	65.0	10.3	10.5	21.1	
Max. survival temp. (°C)	45.0	45.0	50.0	50.0	
Max. operational temp. (°C)	35.0	35.0	30.0	30.0	
Min. operational temp. (°C)	5.0	5.0	0.0	0.0	
Min. survival temp. (°C)	-10.0	-10.0	-20.0	-20.0	

Note: Cable harness mass is included in the main electronics estimate. The mass reserve = 13.5kg. The AIA and GT mass with reserve = 87.6kg SDO-0019

mounted to the spacecraft separately from the telescope. Locating the main electronics box inside the spacecraft could save some mass required for radiation shielding. The optimal location and mounting scheme for the telescope assembly and electronics will be developed with the spacecraft provider during Phase A.

The AIA has no special environmental requirements (beyond GEVS) other than the spacecraft must meet cleanliness requirements appropriate to an EUV telescope as discussed in section §C2.a.10. AIA will require nearly continuous purging with dry nitrogen until shortly before launch. The AIA design provides for easy installation of the flight entrance filters shortly before launch.

The AIA has no significant power variations when in operation. Increased power is required during camera readout and additional heater power is required during eclipses. A preliminary power profile is shown in Table C-8.

Command uploads are minimal, limited to ~200 per day or less. The AIA peak and nominal downlink rate is the same and sized to match the 58 Mbps nominal allocation. If all images are compressed with RICE and

Table C-8. *AIA Power Profile*

Mode	Time	Nominal Power (W)	Reserve (W)	Max. Power (W)
Power Off		0	0	0
Survival Heat On	~2 hrs	42	6.3	48.3
Instrument On	Normal	74	11.1	85.1
Camera Readout (peak)	2 s	80	12.0	92.0
Decontam. On	~4 hrs	114	17.1	131.1
Eclipse	>60 min	116	17.4	133.4

SDO-0059

SRB compression schemes, the reserve on the telemetry downlink is 18%.

C2.a.15. Instrumental Relationships with HMI and AIS

If both this AIA proposal and the Stanford University proposal for the Helioseismic and Magnetic Imager (HMI) are selected, savings will result in mass, power, and developmental costs. AIA and HMI use the same CCD and CCD header designs, identical (except for the number of data channels) camera electronic designs, similar mechanisms, and the same digital and power electronic systems. The two instruments share very similar flight software and image stabilization systems. Combining AIA and HMI eliminates an electronics box and saves 12.4 kg and 21 W. Table C-9 contrasts the individual instruments, the combined instruments, and the AO nominal values. The combined AIA/HMI with reserves compares favorably with the AO nominal resource allocations.

We have discussed further savings if the AIS proposal from SwRI is selected. Mass and power savings in the electronics systems are highly likely, as a single system could service AIA, HMI, and AIS. The AIS might also use the GT error signal for its image stabilization.

Table C-9. *The combined LMSAL AIA (without GT) and Stanford University HMI fits within nominal allocations*

Instrument	Mass (kg)	Power (W)
AIA (LMSAL)	85.3	92
HMI (Stanford U.)	55.6	60
Combined AIA+HMI	128.5	131
AO: All instruments	225.0	443
AO: AIA+HMI	129.0	218

Notes: AIA numbers exclude the GT. Reserves are included.
SDO-0056

C2.b Mission Operations

Simple mission operations and uniform data products are key features of our approach. After initial commissioning we plan to operate with a constant-cadence baseline "script" that cycles through eight of the wavelength channels every 10 s as shown in Fig C-14. The full-sun FOV eliminates the need for pointing decisions; the fixed script eliminates daily planning activities. Uplinks via the Mission Operation Center (MOC) can accommodate program tuning and occasional deviations from the baseline script. Uplinks are compiled at the Science Operation Center (SOC) in Palo Alto and sent to the MOC. The MOC staffing and support described in the AO are adequate for this plan. Monitoring of the images and health and safety are done at the SOC. Our plan reduces operations costs significantly compared to previous missions, while the well-defined and essentially unchanging data acquisition simplifies our data product software.

The baseline program allows up to 2.7 s for all exposures. Final exposure durations will be determined by the science team after initial data are obtained. However, major deviations are unlikely given the detailed knowledge of the optics and thorough calibration procedures described in §C2.a. Each telescope exposes two wavelengths in series. Two CCD readouts use a total of 4.6 s during the 10 s interval. The exposures and CCD readouts for all telescopes are done simultaneously. They could be staggered to read in pairs, if necessary, to reduce peak power usage and buffer memory (descope option).

For some of the high temperature channels, such as Fe XX/XXII 133Å and Fe XVIII 94Å, we expect low counts outside ARs and microflares with the baseline 2.7 s exposures. Summing consecutive exposures on the ground can determine a faint high temperature background in quiet Sun while avoiding both CCD bleeding from overexposed ARs and motion blurring from rapid events. Such summing introduces little noise compared to equivalent long exposures, since the CCD readout noise is less than the number of photoelectrons created by each detected EUV photon.

The very strong signals expected during bright flares require automatic exposure control (AEC). The control-computer hardware is designed to produce the required image statistics while compressing the data (§C2.a.7). Depending on the science objectives, AEC (separately for each channel) may be implemented for each image, on alternating images, or not at all.

Besides the eight channels in the baseline program, images in the visible light and 1700Å channel are taken, but less frequently since they are primarily for context. Each replaces a 1600Å image in the set to maintain the overall 10s cadence. Since HMI produces white light images every minute, the AIA visible light images serve as alignment references.

The baseline program occasionally will be interrupted for calibrations, eclipses, and CCD

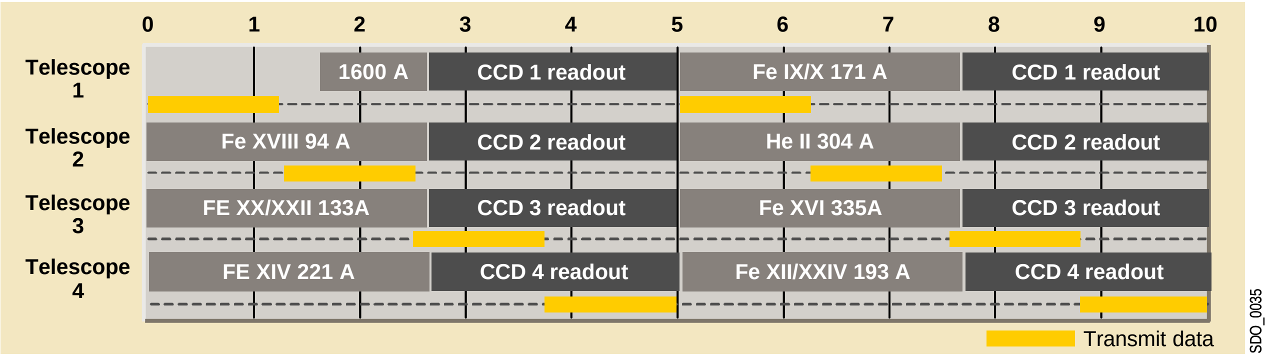


Fig. C-14. Baseline operating mode. *The four telescopes collect data in a sequence that maximizes throughput by overlapping exposures (gray) and readout (black) with data transmission.*

decontamination (if required). These are infrequent and have no major impact on the scientific goals.

Although we plan to run the baseline program for long periods of time without interleaving more specialized observations, the needs and consensus of the scientific community may change, particularly after AIA has accumulated a large database. In that case, scripts optimized for flares, CMEs, or other types of events can be developed for special campaigns. The count level accumulators used for AEC can be used for flare-mode triggers. Higher cadence can be accomplished with partial CCD readouts in some of the channels. A cadence of 2 s is feasible for a 1024×4096 readout, (about 0.8 s for CCD readout leaving about 1s for the exposure time) for a single wavelength.

C2.c Data Collection, Analysis, Archiving

The underlying strategy of the SDO mission is to capture all the data all the time. This avoids the problem faced by previous missions, where either limited time windows, data rates or field-of-view forced planners to guess where and when important events would occur. Thus, many events were missed, or imaged only partly, precursors were not recognized, and events were rarely obtained in their full context. Due to the combination of large-format CCDs, multiple channels, and continuous downlink, AIA produces approximately 600GB of raw telemetry each day, which is 1000 times the typical TRACE daily volume and 300 times the daily volume of the Solar B mission. *To maximize the benefits of the SDO observing strategy we will design a system that can rapidly catalog incoming data and efficiently identify key features in the data that warrant further analysis.*

Our plan for achieving this goal is diagrammed in Fig. C-15. Data will be sent to the AIA SOC on a dedicated data connection of 155Mbps (ATM OC3). This maximum rate guarantees the realtime capture of the data with headroom for retransmissions and other overhead due to hardware failures.

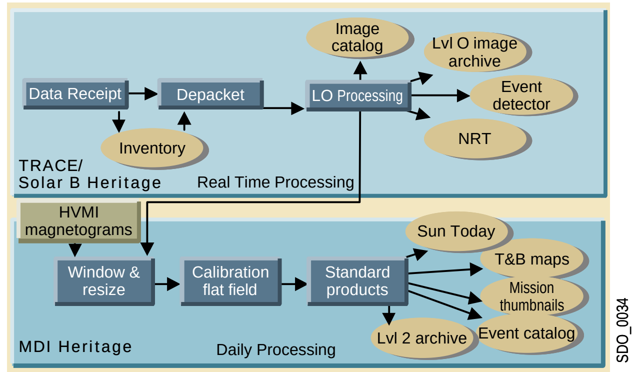


Fig. C-15. AIA data processing pipelines. *Two pipelines handle the AIA data stream. The real-time pipeline captures and catalogs images, and generates NRT products. The daily processing pipeline produces higher level data products.*

We define three levels of data products within our processing pipelines: Level-0 data consist of sorted and cataloged images stored in the original compressed format. This assures data quality while keeping the storage requirements at a minimum. Level-1 data consist of uncompressed sub-images, possibly with calibrations such as flatfield corrections or streak removal applied. Level-2 data include physical measurements, such as temperature or emission-measure maps, and processed movie files.

Data verification occurs at four points within our processing pipelines.

1. The initial inventory process assesses the quality of the incoming data stream.
2. Individual image quality is checked and included in the catalog during the generation of Level-0 data.
3. Image analysts monitor new data regularly at the SOC.
4. Calibration software is continually updated so any distributed data can reflect the most current, up-to-date calibration information.

C2.c.1 Real-time Data Pipeline

At the SOC, a real-time processing pipeline receives the data stream, inventories and sorts the data packets, and generates Level-0 and

Near Real Time (NRT) data products at a cadence of one image per 1.25 s. The pipeline has sufficient capacity to cope with network and hardware faults. Presently we process one 1024×1024 pixel TRACE image each second during batch-processing jobs run daily. Although the total data volume of AIA is much higher than TRACE, the TRACE data is acquired and processed in bursts throughout the day. Processing the continuous AIA data stream requires only a factor of 12 increase in sustained throughput over the TRACE burst rate. This is manageable now with our existing software system on an 8-processor computer recently purchased by LMSAL as a fixed asset.

The real-time pipeline includes simple image processing capabilities such as summing images to reduce noise or searching for sudden brightenings or dimming through differencing and thresholding of image pairs. Such NRT data products are available within minutes of their acquisition. Event flags are set and made available to forecasting agencies and other interested parties via our web site within seconds of being processed.

Level-0 AIA data are similar to that of TRACE; the excellent cosmetics, freedom from artifacts, and low-noise of the CCDs results in images that are scientifically useful with minimal processing. We therefore follow the TRACE strategy of simply cataloging incoming images and putting them into the Level-0 archive. New data in this archive are typically released to researchers and other community members within minutes of receipt.

C2.c.2 Higher Level Data Products

Regular processing and archiving beyond Level 0 is limited to a subset of the data. We foresee three main categories of Level 2 products:

1. *The Sun Today*. Movies of all AIA data streams are frequently updated to display the most recent 12-24 h of solar activity.
2. *Mean temperature and magnetic field maps*. Using DEM analysis on preliminary calibrated data we will provide Quick-Look maps throughout the day for use in mission planning and support of other solar and heliospheric missions. We will also use the magnetogram data from HMI to generate associated potential field and, eventually, force-free extrapolations.
3. *Full Mission Thumbnails*. Resampled, 1024×1024 images of all wavelengths for every minute of the mission will be online for analysis by researchers and to guide searches into the full-resolution Level-0 dataset.

The pipeline for processing this data is similar to that of our companion HMI proposal from Stanford, as well as that for the AIS from SwRI. We base it upon the highly-refined model used for MDI. If the other two proposals are funded, we can share in the development of this pipeline, thereby reducing cost and increasing reliability (see § E2.8).

C2.c.3 Preliminary Data Analysis

The large data volume of AIA requires an efficient system for data inspection. Preliminary data analysis takes place in the SOC, where image analysts are presented with a system capable of displaying a single 16Mpixel image or eight HDTV images. This system contains a complete stet of full-resolution AIA data for the past 24 hours, as well as HMI magnetograms and selected sets of other SDO data, in a form that can readily be displayed as movies. During the automated creation of these movies, events identified during real-time processing are incorporated and cross-referenced.

This allows image analysts and (visiting) scientists to simply sit down at any time in front of dedicated hardware to review and learn from the data. A first scan through a 24-h movie in each channel takes only 5 minutes when played at video rates. These movies can be compared on adjacent screens, or blended with each other or with pre-made movies of, for example, the dominant temperature for each pixel, or with magnetograms. Features and events detected by software can be overlaid to guide visual inspection. The analysts can then return to events that warrant further analysis. They can replay movies at any speed, while panning, zooming, or blending movies using customized hardware and software being developed by LM.

Using internal research funding and fixed assets investments for computer and display hardware, Lockheed Martin has been prototyping such a system for the past few years; LM is committed to continue its development in support of AIA. We have already demonstrated real-time display and processing of multiple 1024×1024 pixel image sequences at recent AGU meetings using TRACE and EIT data sets. The software tools developed with internal funds will continue to be distributed and maintained via SolarSoft as we have throughout the Yohkoh and TRACE missions.

The full AIA system allows us to efficiently catalog events. No time is required of the image analysts for tedious and unproductive data processing: all of their time is effectively spent on data analysis, describing events in a publicly available catalog, and learning from what they observe.

Analysts identify and catalog "standard" events, such as prominences or CMEs and discover new classes of events, such as the oscillating loops discovered in the TRACE data. They will be further aided by the use of feature recognition software, which will autonomously search the day's data. As these algorithms evolve, they are continually applied to the full Level-0 archive to locate and record previously neglected or unrecognized events. All these events are described online as a detailed event catalog in a standard format with search interfaces for specific entries or groups of entries.

C2.c.4 Data Archiving and Distribution

Data reside online at the SOC for a fixed duration before being written to near-line tape or DVD-ROM libraries. Data older than one year are stored off-line, but are available on request within a day. All data are backed up with copies distributed to GSFC for disaster recovery. Level-0, some Level-2, and associated calibration procedures will eventually be transferred to the permanent archive as specified by NASA.

Level-0 images are stored in individual files with metadata (header information) for each image directory stored as multi-record files. Scientific queries into this archive are mediated by web or other user interfaces. Using the Full-Mission Thumbnails and event catalogs, researchers locate and winnow the data required for their projects. They then request the full-resolution data for their region and interval of interest. Software interfaces access the archive, apply the current standard calibrations (if requested), and deliver Level-1 data in FITS or other formats. Since calibration procedures typically evolve during mission operations, this approach assures that the highest quality Level-1 data is always distributed to users, without demanding continual churning of the entire database.

It is essential to both the ILWS program and the SDO mission that data access and sharing between instrument teams be as transparent as possible. We will explore a variety of avenues for accomplishing this goal. The SOC will participate and coordinate with the Virtual Solar Observatory (VSO) [80] by making catalogs available and developing interfaces to the VSO. They will deploy web services, similar to that currently provided by TRACE. New technologies, including Grid-based interfaces [81] or software agent technologies [82], will be incorporated as they mature. In addition, our team will investigate techniques for embedding theoretical and computational models as integral parts of the data analysis system. These efforts will be overseen by J. Gurman, N. Hurlburt (*coordinator*), and R. Shine.

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D1 AIA EDUCATION AND PUBLIC OUTREACH

Overview and Objectives. "We all live in the atmosphere of the Sun." This comment from the AIA PI underscores how easily a dramatic object in our natural world can be taken for granted. SDO's comprehensive study of our star and its effects on Earth provides a singular opportunity to engage the public in scientific exploration and to work with educators to improve the teaching of science, math, and technology. Using the public's interest in SDO as a "hook," we intend to improve science literacy and public understanding of the Sun's role in the Earth's environment. Our key E/PO goal is to produce and disseminate solar science related information, materials, and activities to aid educators and the general public in understanding the star we live with. Multiple partnerships provide leverage to expand the scope and effectiveness of our products. Our ultimate mission is to improve science literacy by inspiring and engaging people's imagination.

Activities. We will draw upon the resources of our existing partnerships, forge new collaborations, and jump-start a program based on proven activities. Our multi-faceted, highly leveraged E/PO program will have national impact. Using undergraduates trained in the presentation of science materials, we will extend our reach to schools to field-test and assess developed materials and activities. Similar programs have been piloted at Co-I institutes with great success.

The PI and Co-I institutes already have dynamic E/PO programs. These feature the award-winning YPOP and Solar Center websites, as well as the TRACE website [83]; the Solar-B exhibition at the Chabot Space and Science Center [83]; SAO's innovative research-based science curricula projects [84]; teacher training workshops and media; science museum partnerships; and a wide range of popular curricula and educational resources that highlight the superb imagery and findings of previous missions. Scientists routinely visit local schools to present videos, give talks and observing sessions, and distribute educational materials. Many participate in Project ASTRO, a national astronomy education program funded by the NSF and administered by the Astronomical Society of the Pacific. Throughout the Yohkoh and TRACE programs the LMATC has provided posters, video materials, and displays at teachers conferences and scientific meetings for the purpose of education and public outreach. More than 200,000 posters and 30,000 tapes, CD-ROMs and DVDs have been produced from internal funds. Lockheed Martin is committed to a similar level of effort for the SDO mission.

We propose to expand upon this successful work by partnering with Stanford's Haas Center for Public Service [85] and collaborating with various science and education institutes. This will produce a dynamic, coordinated, and highly-leveraged E/PO program which addresses our broader goals through three specific means:

a. **Student Involvement/Service Learning:** We will integrate university undergraduate students into our E/PO efforts. The students will work with the science team to develop, field-test, and assess educational materials. Students will also assist the science team in developing information and resources for the press and general public. Some students will be involved in developing the instrument and data analysis.
b. **K-14 Activities and Involvement:** With educators, we will develop, test, and assess a unified collection of science educational material. The goal is to quickly begin enhancing science literacy to make an immediate impact on classrooms even before SDO launch and before mission data become available. Once students and the public are excited by the Sun and its importance, they will be more interested by the mission and eager to learn about its find-

ings. Students and scientists will collaborate on dissemination of the material through teacher workshops, master teacher programs, NSTA, and partnering institutes. Resources supporting the activities will be submitted to NASA CORE for distribution.

c. Public Outreach and Access: After launch, we will focus on communicating the research results of the mission to the press and general public. To share the excitement of discovery, we will provide a direct link to the latest data AND key scientists. Using our successful YPOP website as a model, we will feature live solar image feeds, daily "solar weather" reports, weekly solar "nuggets", predictions of solar activity, a panel of solar astronomers to field questions online, and chat rooms for the public and educators. Existing relationships with the press and science magazines will be nurtured, as new relationships are established, so that the E/PO team will be an appropriate first source of information about solar activity. With the support of our students, we will prepare background materials to support NASA press releases and provide a reference to the general public. We will collaborate with science museums to distribute these materials.

Partnerships. We have existing or newly arranged partnerships with a variety of science and education institutes. These include Chabot Space and Science Center, Oakland, CA; The Tech Museum of Innovation, San Jose, CA; The Morrison Planetarium, California Academy of Sciences (CAS), San Francisco, CA; Lawrence Hall of Science, Berkeley, CA; the Institute for Imagination and Innovation in Science Education (IIISE, a community college group), Milpitas, CA; the Haas Center for Public Service, Stanford, CA; the School of Education, Stanford; and the Science Education Department at SAO. Participation is summarized in Table D1-1.

Collaboration with the HMI Team. If the HMI proposal by Stanford University (with significant contributions from LMSAL) is selected, we will collaborate extensively with the HMI team. Participants in the HMI mission proposal have significant expertise in developing highly successful E/PO programs and materials. Of particular note are the SOLAR Center educational website, webcasts televised by NASA TV to tens of thousands of students, and popular curricula and educational resources that highlight the superb imagery and findings of previous missions. Drawing upon their existing partnerships with students, science museums, and educational institutes in the various local areas, we can a) Pool resources to jointly develop programs and materials that otherwise might be too costly or extensive; b) Broaden our ability to distribute materials; c) Share coordination and management roles to minimize the need for additional staff; d) Leverage off existing programs; e) Coordinate student programs and share resources and experiences; f) Test our educational products in more diverse environments. Whether the HMI proposal is selected or not, Stanford University, through its collaboration with LMSAL in the Stanford Lockheed Institute for Space Research

Table D1-1. *Matrix of Co-I/Partner Participation*

Institution	Student Involvement	K-14 Curr. Devel.	Teacher Work-shops	Assessment Support	Multi-media Development	Distance Learning Support	Distribution of Materials	Access to under-served Groups	Public/ informal ed.
LMSAL	X	X		X	X		X	X	X
Stanford-Haas	X			X	X			X	X
MSU	X	X	X	X	X	X	X	X	X
SAO	X	X	X	X	X	X	X	X	X
Stanford	X	X	X	X	X	X	X	X	X
Chabot SSC	X		X				X	X	X
Tech Museum	X		X				X	X	X
Morrison Planetarium (CAS)	X		X				X		X
Lawrence Hall of Science		X	X	X			X	X	
IIISE		X					X		
NASA CORE							X		

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(SLISR) will be an integral part of the AIA E/PO team. If the HMI proposal by Stanford University is not selected, we will study during Phase A how to fully implement and fund the collaboration with the Haas Center (see §D1.b for details).

Implementation. We will train our involved students through a series of seminars and week-long summer sessions. The Haas Center and partner institutes will pair the students with elementary, middle, and high schools in the local area to field-test science related materials, assess their value, and adjust the activities accordingly.

LMSAL, Stanford University, Montana State University (MSU), and SAO have programs that involve science and technology students with educational and public service institutes. For example, the Science Education Department (SED) at SAO has been a national leader in developing innovative research-based science curricula. In addition, we propose to directly partner with Stanford's Haas Center for Public Service [85] to leverage our educational outreach programs. Haas supports over 40 programs that connect students with outside educational and public service institutes. Haas is nationally recognized as first [86] amongst this type of organization. Working with its partnering institutes, the Haas Center is able to provide selection, training, support, and management of students to work with the science team. Science Fellows, undergraduates chosen competitively, will be provided with a small incentive stipend.

Haas also has a unique program to integrate service learning into the classroom. Working with faculty, assignments are generated which benefit community institutes or courses are adapted to a particular goal such as "Communicating Science." UC Berkeley has a similar program and the director reports many positive remarks from students on how the course "changed their life" and that some have "gone on to focus on careers in education as a result of participating in the program." [87]

The Haas Center has success with social science service learning and is interested in extending this program to science and technology. Possible service-learning opportunities include a public-oriented online magazine related to Living with a Star, multimedia presentations of mission results, generation of educational materials, and supporting press releases. We expect to work with 20-30 students a year in this service-learning model. We will work with Haas and local faculty to develop an effective model program, exportable to a variety of institutes.

The western sites and activities will be coordinated through LMSAL, Stanford, and MSU. SAO will coordinate eastern activities.

Yearly Focus Model. We will focus on developing one major, coordinated educational curriculum or program each year, for the first 5 years of the mission. Educational materials will support the focus; student Fellows will test run the activities; teacher and master teacher workshops through partnering science museums will train use of activities; webcasts and videos will present the focus activities; and DVDs will allow for use of the material in distance learning. Example Yearly Focus Projects include:

- Creating a solar-based interactive planetarium program appropriate for use with the Starlab portable planetariums. [88] Many have emphasized the need for sun-related programs for Starlab.
- Developing a Great Expectations in Math and Science (GEMS) guide on a topic associated with living with an active star. [89]
- Developing a collection of teacher kits and grade-appropriate curricula to accompany our existing low-cost spectroscope. [90]
- Creating activity sets in tracking and understanding the Sun, suitable for a wide age range, school, and family participation. [91]

The curricula, material, and activities will be hands-on, inquiry based, appropriately related to the National Science Education Standards [92]. We will coordinate our program with the interests of the OSS and LWS programs [93]. The basic concept to teach is that the Sun is an active, variable star that has significant impacts upon the Earth. We will draw upon existing resources and materials, presenting them in new and interesting ways.

Evaluation/Assessment. Assessment provides important feedback to both instructors and students. There is an excellent research base in what constitutes effective educational assessment and evaluation [94]. We will rely heavily on this base to guide the development of assessment aspects for our programs. For the educational activities and materials, and the model programs, specific goals will be identified and "best practices"-based assessment techniques applied to evaluate the extent to which goals are being achieved.

Stanford's Haas Center and MSU have particular expertise in evaluation and metrics. The E/PO team will work collaboratively to prepare professional quality evaluation materials and to carry out assessment of the activities, curricula, and model programs.

Involvement. The PI and Co-Is will be closely involved in all aspects of the E/PO program. Each of the LMSAL, Stanford, MSU, and SAO teams include scientists responsible for their institute's AIA E/PO. Scientists will work with educators to develop materials, train Science Fellows in their use, and collaborate on dissemination of the material through teacher workshops and partnering institutes. Additionally, each Co-I not on the E/PO team will provide 1-4 days of E/PO each year. These will likely be seminars for Science Fellows, teacher workshops, or work on press releases. Scientists will also present the materials at NSTA, AGU, and similar conferences to reach a large audience and to share E/PO experiences with other scientists.

Underrepresented Groups. Our partnering institutes have experience and interest in involving both women and minorities in education and research. MSU has longstanding associations with the American Indian community, especially in their partnerships with Montana's seven tribal colleges in the Montana Space Grant Consortium (MSGC) and the American Indian Research Opportunities consortium (AIRO). Boston and the San Francisco Bay Area are amongst the most ethnically and culturally diverse communities in the nation. The Haas Center has outreach contacts and programs with minority-based schools in the area. LMSAL supports programs to encourage women to enter scientific professions. Our partner museums have teacher training and master teacher programs that particularly target minority populations. We will work with the student groups and within our institutes to actively recruit women and minorities into our student Fellow programs, where they can serve as excellent role models to our K-14 classrooms. We will particularly focus on liaisons with local educational institutes involving minorities and women. We will work with educators to assure our curricula and activities are culturally appropriate to the diversity in our areas.

Organization and Management. We will establish an Oversight Board to direct the planning and development of the E/PO project. The Board will be responsible for overall decision-making, choosing the yearly focus, evaluating possibilities for activities and materials, and for key creative decisions. Most importantly, to encourage frequent contact with and input from scientists, the Board will maintain a steady stream of communication about the E/PO efforts within the science teams and with NASA. The Oversight Board will consist of B. De Pontieu (LMSAL), D. Scherrer (Stanford), D. McKenzie (MSU) and E. DeLuca (SAO).

D1.a AIA Education and Public Outreach Budget Tables

BUDGET SUMMARY for
AIA Education/Public Outreach Proposal

For (check one):

___ Total Period of Performance from (M/Y) ________ to ________

/or/

_X_ Year __1_ of _9_ from (M/Y) __Oct 02 to ___Sept 03

1. Direct Labor (salaries, wages, and fringe benefits)	$18,622
2. Other Direct Costs	
a. Subcontracts	
MSU	$112,551
SAO	$1,447
Stanford University	
b. Consultants	
c. Equipment	
d. Supplies	
e. Travel	$1,000
f. Other	$414
3. Facilities and Administrative Costs	$16,893
4. Other Applicable Costs	$6,147
5. SUBTOTAL-Estimated Costs	$157,074
6. Less Proposed Cost Sharing (if any)	(83,150)
7. Total E/PO Estimated Costs	$73,924

BUDGET SUMMARY for
AIA Education/Public Outreach Proposal

For (check one):

___ Total Period of Performance from (M/Y) ________ to ________

/or/

_X Year ___2 of ___9 from (M/Y) _Oct 03 to_Sept 04

1. Direct Labor (salaries, wages, and fringe benefits)	$19,074
2. Other Direct Costs	
a. Subcontracts	
MSU	$115,702
SAO	$18,270
Stanford University	
b. Consultants	
c. Equipment	
d. Supplies	
e. Travel	$1,000
f. Other	$376
3. Facilities and Administrative Costs	$17,218
4. Other Applicable Costs	$7,647
5. SUBTOTAL-Estimated Costs	$179,287
6. Less Proposed Cost Sharing (if any)	(85,478)
7. Total E/PO Estimated Costs	$93,809

BUDGET SUMMARY for
AIA Education/Public Outreach Proposal

For (check one):

___ Total Period of Performance from (M/Y) ________ to ________

/or/

_X Year __3_ of __9_ from (M/Y) Oct 04__ to Sept 05_

1. Direct Labor (salaries, wages, and fringe benefits)	$19,530
2. Other Direct Costs	
a. Subcontracts	
MSU	$118,942
SAO	$18,848
Stanford University	$50,000
b. Consultants	
c. Equipment	
d. Supplies	
e. Travel	$1,000
f. Other	$333
3. Facilities and Administrative Costs	$17,320
4. Other Applicable Costs	$11,784
5. SUBTOTAL-Estimated Costs	$237,757
6. Less Proposed Cost Sharing (if any)	($87,872)
7. Total E/PO Estimated Costs	$149,885

BUDGET SUMMARY for
AIA Education/Public Outreach Proposal

For (check one):

___ Total Period of Performance from (M/Y) ________ to ________

/or/

_X Year __4_ of __9_ from (M/Y) Oct 05__ to Sept 06_

1. Direct Labor (salaries, wages, and fringe benefits)	$20,049
2. Other Direct Costs	
a. Subcontracts	
MSU	$122,272
SAO	$19,427
Stanford University	
b. Consultants	
c. Equipment	
d. Supplies	
e. Travel	$1,000
f. Other	$320
3. Facilities and Administrative Costs	$17,649
4. Other Applicable Costs	$7,970
5. SUBTOTAL-Estimated Costs	$188,687
6. Less Proposed Cost Sharing (if any)	(90,332)
7. Total E/PO Estimated Costs	$93,355

BUDGET SUMMARY for
AIA Education/Public Outreach Proposal

For (check one):

___ Total Period of Performance from (M/Y) ________ to ________

/or/

_X Year __5_ of __9_ from (M/Y) Oct 06__ to Sept 07_

1. Direct Labor (salaries, wages, and fringe benefits)	$20,385
2. Other Direct Costs	
a. Subcontracts	
MSU	$125,696
SAO	$22,734
Stanford University	
b. Consultants	
c. Equipment	
d. Supplies	
e. Travel	$1,000
f. Other	$317
3. Facilities and Administrative Costs	$17,945
4. Other Applicable Costs	$8,368
5. SUBTOTAL-Estimated Costs	$196,445
6. Less Proposed Cost Sharing (if any)	($92,861)
7. Total E/PO Estimated Costs	$103,584

BUDGET SUMMARY for
AIA Education/Public Outreach Proposal

For (check one):

___ Total Period of Performance from (M/Y) ________ to ________

/or/

_X Year __6_ of _9__ from (M/Y) Oct 07__ to Sept 08_

1. Direct Labor (salaries, wages, and fringe benefits)	$21,186
2. Other Direct Costs	
a. Subcontracts	
MSU	$129,215
SAO	$47,783
Stanford University	
b. Consultants	
c. Equipment	
d. Supplies	
e. Travel	$1,000
f. Other	$320
3. Facilities and Administrative Costs	$18,651
4. Other Applicable Costs	$10,597
5. SUBTOTAL-Estimated Costs	$228,752
6. Less Proposed Cost Sharing (if any)	($95,461)
7. Total E/PO Estimated Costs	$133,291

BUDGET SUMMARY for
AIA Education/Public Outreach Proposal

For (check one):

___ Total Period of Performance from (M/Y) ________ to ________

/or/

_X Year _7__ of __9_ from (M/Y) Oct 08__ to Sept 09_

1. Direct Labor (salaries, wages, and fringe benefits)	$21,778
2. Other Direct Costs	
a. Subcontracts	
MSU	$138,909
SAO	$32,075
Stanford University	
b. Consultants	
c. Equipment	
d. Supplies	
e. Travel	$1,000
f. Other	$320
3. Facilities and Administrative Costs	$19,172
4. Other Applicable Costs	$10,012
5. SUBTOTAL-Estimated Costs	$223,266
6. Less Proposed Cost Sharing (if any)	($98,134)
7. Total E/PO Estimated Costs	$125,132

BUDGET SUMMARY for
AIA Education/Public Outreach Proposal

For (check one):

___ Total Period of Performance from (M/Y) ________ to ________

/or/

_X Year _8__ of _9__ from (M/Y) _Oct 09_ to _Sept 10

1. Direct Labor (salaries, wages, and fringe benefits)	$22,390
2. Other Direct Costs	
a. Subcontracts	
MSU	
SAO	$33,068
Stanford University	
b. Consultants	
c. Equipment	
d. Supplies	
e. Travel	$1,000
f. Other	$320
3. Facilities and Administrative Costs	$19,710
4. Other Applicable Costs	$6,944
5. SUBTOTAL-Estimated Costs	$83,432
6. Less Proposed Cost Sharing (if any)	
7. Total E/PO Estimated Costs	$83,432

BUDGET SUMMARY for
AIA Education/Public Outreach Proposal

For (check one):

___ Total Period of Performance from (M/Y) ________ to ________

/or/

_X Year __9_ of _9__ from (M/Y) Oct 10 to Sept 11

1. Direct Labor (salaries, wages, and fringe benefits)	$23,017
2. Other Direct Costs	
a. Subcontracts	
MSU	
SAO	$6,350
Stanford University	
b. Consultants	
c. Equipment	
d. Supplies	
e. Travel	$1,000
f. Other	$320
3. Facilities and Administrative Costs	$20,263
4. Other Applicable Costs	$4,924
5. SUBTOTAL-Estimated Costs	$55,874
6. Less Proposed Cost Sharing (if any)	
7. Total E/PO Estimated Costs	$55,874

BUDGET SUMMARY for
AIA Education/Public Outreach Proposal

For (check one):

_X Total Period of Performance from (M/Y) Oct 03__ to Sept 11

/or/

__ Year ____ of ____ from (M/Y) ________ to ________

1. Direct Labor (salaries, wages, and fringe benefits)	$186,032
2. Other Direct Costs	
a. Subcontracts	
MSU	$863,287
SAO	$200,000
Stanford University	$50,000
b. Consultants	
c. Equipment	
d. Supplies	
e. Travel	$9,000
f. Other	$3,040
3. Facilities and Administrative Costs	$164,821
4. Other Applicable Costs	$74,392
5. SUBTOTAL-Estimated Costs	$1,550,572
6. Less Proposed Cost Sharing (if any)	($633,288)
7. Total E/PO Estimated Costs	$917,284

D1.b AIA E/PO Budget Narrative

Our E/PO proposal is based on a close partnership with the HMI E/PO proposal led by the solar group at Stanford University, who are also a partner in the AIA E/PO proposal. It has the potential for generating a dynamic and exciting program, especially with respect to the proposed collaboration with the Haas Center for Public Service at Stanford. Although not included in the AIA E/PO budget summary, Stanford University and the Haas Center are willing to cost-share $1.4M towards the HMI E/PO proposal with which we will collaborate intensively. This cost-sharing by Stanford University under the HMI proposal will involve:

a) Provide .75 FTE to support a Haas assessment and metrics expert (for first 4 years starting immediately after selection).
b) Provide .25 FTE clerical staff support through the Undergraduate Studies division, to assist with the student programs (for first 4 years, starting immediately after selection).
c) Support of 1 FTE for Haas student program management, for the initial 6 months of the program. This will allow us to get a student Science Fellow program in place for the first year.
d) Waiving of overhead on the HMI supported Haas staff person (4 years).
e) Haas will seek funding for the Science Fellow stipends through various charitable trusts (for the full 10 years of the mission).

Should the Stanford-led HMI proposal not be selected, we will study during Phase A how to implement an AIA-only collaboration with the Haas Center. In such an event, our Phase A study will request additional funding beyond the normal E/PO scope. According to the answers to official questions about SDO, such funding might come from additional sources rather than being charged against the proposed instrument. If additional funding is not available (and HMI by Stanford is not selected) we will redefine our E/PO proposal activities.

LMSAL

The PI institution is part of the Lockheed Martin Advanced Technology Center (LMATC). The LMATC has, throughout the Yohkoh and TRACE programs, provided posters, video materials, and displays at teachers conferences and scientific meetings for the purpose of education and public outreach. More than 200,000 posters and 30,000 tapes, CD-ROMs and DVDs related to solar physics have been produced and distributed from internal funds (at a cost of about $20,000 per year). Lockheed Martin is committed to a similar level of effort for the SDO mission (not shown in the budget pages). In addition to this internal support, LMSAL E/PO staffing will be at a constant 0.15 FTE level from year 1 to 9 [see 1) Direct Labor, 3) Facilities and Administrative Costs and 4) Other Applicable Costs, for a total of $42,076 per year, in FY2003 $].

This will mostly support a scientist (B. De Pontieu) who will:

a) coordinate the overall AIA E/PO program, in close collaboration with D. Scherrer from Stanford/HMI;
b) coordinate with the overarching LWS E/PO program;
c) provide educational material and resources for the press and general public, both through the service learning at the Haas center, the teacher workshops, and also more directly during the years after launch.

Some LMSAL effort will also go to web-programming for the AIA public website, in close coordination with the MSU and SAO web-site efforts. Travel funds will support coordination with the overarching LWS E/PO program (at GSFC).

In addition, scientist Co-Is from LMSAL and partner institutes will donate 1 to 4 days of their personal time per year of effort.

The LMSAL AIA E/PO activities will also be merged with the Solar-B E/PO activities of LMSAL, which involve a close collaboration with the Chabot Space Science Center in Oakland.

Stanford University

Funding for the E/PO activities of the solar group at Stanford University will be through the HMI E/PO proposal, except for $50,000 in year 3 (FY 2005) from the AIA E/PO budget. This amount will help support work on developing a Great Expectations in Math and Science (GEMS) guide on a topic associated with living with an active star.

Montana State University

The AIA E/PO activities of Montana State University will occur from year 1 through 7 (FY 2003 through 2009) and are closely tied in with the HMI E/PO activities through the Haas Center. These activities are partially supported by cost-sharing through the Montana Space Grant Consortium (MSGC). The total amount of the MSU subcontract (line 2a) on the budget pages includes this cost sharing by the MSGC at $83,150 per year (in FY 2003 $) from year 1 through 7. The cost sharing by MSGC is subtracted on line 6 of the budget pages. The net MSU cost to be covered by the AIA E/PO budget is $29,401 per year from year 1 through 7 (in FY 2003 $).

The AIA-related E/PO activities at MSU include (fraction/percentage in brackets indicates AIA cost, the remaining part will be covered by MSGC):

a) Graduate Research Assistant #1, for logistical management of the student presenter teams: liaising with the teachers, scheduling the events, managing the tangible materials (0.3 FTE)
b) Mr. Mike Murray, Assistant Director of MSGC: oversight of recruitment & training of student presenters, materials development and assessment (0.1 FTE)
c) Graduate Research Assistant #2, from Physics & Astronomy Education Research group: evaluation and assessment (0.1 FTE)
d) Supplies: posters & handouts (20% of costs)
e) Travel within Montana: getting the presenters to the schools and back again (20% of costs)
f) Travel from Montana to Palo Alto for 6 students for 3 days, or 3 students for 6 days (100% of cost)
g) Stipends for student presenters who go to classrooms (15% of cost)
h) Travel from Montana to Palo Alto for Dr. D. McKenzie for oversight board meetings (100% of cost).

Smithsonian Astrophysical Observatory

The AIA E/PO activities of the Smithsonian Astrophysical Observatory will commence in July 2005 and run from year 2 through year 9 (FY 2004 to 2011). Dr. Ed DeLuca will direct the SAO AIA E/PO efforts, conferring regularly with Dr. R.B. Ward, Project Director for AIRES and SEDNet and Adjunct Professor of Astronomy, Middlesex (MA) Community College, who will be responsible for the contributions of the Science Education Department at SAO. On average, the AIA E/PO funding to SAO will support a 0.3-0.4 FTE at SAO. The overall theme of the SAO program, which targets students in grades 5-9, is “The Sun-Earth Connection: An Ever Changing Partnership”. As part of this program, SAO will:

a) Develop and disseminate regionally a short discovery-based module (teacher manual and student materials) focused on light, color, sunlight, daytime astronomy, energy, and spectroscopy. The module will introduce students to some fundamental characteristics of the active Sun and some effects of that activity on Earth. These complementary materials will be for use with grade 5-9 students and general audiences.

b) Present staff-led workshops at major science conferences or conventions.
c) Collaborate with SECEF and its Aerospace Education Specialists in the region.

The strategies used will include:

a) Developing the classroom module, drawn primarily from the numerous SED's explorations now part of other curricula or other programs, and when necessary, creating new materials.
b) Piloting the module in local grade 5-9 classrooms (10-12 sites), working with teachers already a part of one or more of the SED's professional development networks.
c) Arranging for the publication of all printed materials.
d) Disseminating these materials regionally through existing SED partners, the NASA Aerospace Educators, and mathematics and science associations.
e) Collaborating with the NASA Forum partner to integrate SDO-related themes into the Forum workshops and educational outreach.

Time-phased Activities

Phase A

During Phase A, we will work out details of coordinating with LWS and jump-starting our E/PO program to have it effectively running by Phase B. A detailed E/PO plan and budget will be prepared, including timelines, staffing, and implementation details. The yearly foci for the first 2 years will be determined.

Phase B

We will implement the first of the yearly foci. After testing by the Science Fellows, we will organize teacher and master teacher workshops through partnering science museums. We will also develop videos and DVDs for use in training and distance learning. Preliminary work on the public website will be started.

Phase C/D

During Phase C/D we will develop and implement the next four coordinated educational curricula, one for each year. Dissemination packages will be developed, for use at professional conferences such as the National Science Teachers Association or the AGU educational sessions. During this phase, we will also further develop our website.

Phase E

During Phase E, we will focus on communicating the research results of the mission to the press and general public. On our website we will feature daily "solar weather" reports, weekly solar "nuggets", predictions of solar activity, and so on. We will also provide a continuous real-time videostream on the web that can be used for publicity and public outreach, for display in museums and science centers, and for the press (e.g. when "violent" events occur on the Sun). We will also support NASA press releases by providing background material.

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D2 Technology Plan

The proposed AIA instrument contains little new technology. All of the techniques being used have been successfully applied in space previously or are modest extensions of such technologies.

The 4096×4096 pixel CCDs are certainly state-of-the-art for space use, but our vendor, Marconi Applied Technology, has already produced 2048×4096 devices for our Solar-B/FPP instrument (see FO2-2, §C2), the larger devices are a straightforward next step. Other than a factor of two increase in one dimension, other relevant characteristics (such as noise, cosmetics, uniformity, radiation hardness, etc.) are not new.

The use of Si/SiC multilayers for the 304 and 335Å channels and Y/Ru (with a layer of YC_2 for stability) for the 94Å channel perhaps qualifies as new technology. EUV multilayer technology is well developed and continues to be refined, both for space and ground-based applications. Si and SiC are common materials that can be easily applied with standard techniques. They will provide higher reflectance and narrower band performance than several other viable options at these longer wavelengths. Samples will be extensively tested to verify performance and long-term stability prior to committing them to the final design. If problems are encountered, we will retreat to using established coatings such as B_4C/Si well before there is an issue with schedule or cost. The extension in image taking cadence that might result would be modest and scientifically acceptable. Y/Ru multilayers have been fabricated and tested over the past several years and proven to be stable both in the laboratory and in rapid aging tests at high temperatures. If additional testing early in the program indicates any problems, we will go to Y/Mo which is known to be acceptable. About 15% loss in sensitivity would result, which might impact cadence by about half this as the read-out times are not affected.

As a result of having very little, if any, new technology, AIA is a low risk program from a technical/performance point of view.

D3 Small Disadvantaged Business Plan

LMATC will work to ensure the highest level of small business and small disadvantaged business support to the AIA program. LMATC is a part of Lockheed Martin Space Systems Company-Missiles & Space Operations (LMSSC) which has an award-winning SBP (Small Business Program) that vigorously seeks small, minority, and woman-owned businesses and historically minority colleges and universities that have demonstrated ability to supply or develop products and expertise suitable for LMSSC programs. Lockheed Martin's government approved *Master Subcontracting Plan for Small Business Concerns* is available upon request.

LMSSC will submit a small business/small disadvantaged business subcontracting plan for Phase A upon contract award. The subcontracting plan for Phases B through E of the AIA program will be submitted at the end of Phase A. We already have many established relationships with SB/SMB as a result of our current and previous program experience on MDI, TRACE, SXI, SXT, and Solar-B. During Phase A we will aggressively work with LMATC's Small Business Office to identify small and small disadvantaged businesses that can support AIA. During the proposal phase we have identified the following small businesses that are under consideration for becoming part of our supplier team on the AIA program:

- Palo Alto Village Travel (woman-owned)
- Acton Research Corporation (SB)
- Luxel Corporation (SB)
- H Magnetics (SB)

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E MANAGEMENT AND SCHEDULE

The AIA team is dedicated to achieving the following top-level objectives:

- Conduct the scientific investigation described in §C1 of this proposal.
- Design, develop, fabricate, test, integrate, calibrate, and operate the AIA instrument, described in §C1, to acquire the necessary observational data.
- Accomplish the goals of the NASA/OSS education and public outreach strategy, as well as those for developing new technologies and involving small disadvantaged businesses.
- Manage the personnel, resources, tradeoffs, and interfaces to accomplish the program on schedule, within budget, and in a manner that minimizes risks and maximizes the science return on expenditures.

To accomplish these objectives we have assembled an extremely strong and experienced team led by Dr. A. M. Title as Principal Investigator. The majority of the LMSAL team has worked together on prior, PI-class, solar physics space missions, including OSO-8/MXRH, SMM/XRP, Spacelab-2/SOUP, Yohkoh/SXT, SOHO/MDI, and TRACE. Primary current programs are GOES/SXI, STEREO/SECCHI, and Solar-B/FPP and XRT. Besides the instrumentation being developed at LMSAL, a significant amount of instrumentation will be developed at SAO under the direction of Dr. L. Golub, and the CCD camera systems will be provided by RAL and MSSL of the UK, in a joint program led by Prof. J. L. Culhane. These individuals, and their institutions, have worked together on many prior programs. In particular, SAO and LMSAL were responsible for the TRACE investigation, which formed the foundation for the AIA on SDO, and are now collaborating on XRT. Collaborations with our UK partners extend back to the days of OSO-8 and were quite extensive on SMM where MSSL, RAL, and LMSAL were equal partners (Co-PIs) on the XRP investigation.

The AIA management approach will continue to use the approaches that have evolved in successfully performing the series of programs noted above. In addition to the heritage of the personnel and institutions, significant (NASA funded) heritage of hardware, software, and ground data processing capabilities, combined with a thorough understanding of the GSFC approach to instrument development, will enable us to accomplish this major investigation at modest cost and with minimal risk. Further efficiencies will be realized if NASA selects the Stanford proposal for the HMI, since that instrument will be developed by LMSAL sharing many of the same hardware, software, and management elements as AIA. In addition, we have had preliminary discussions with Dr. D. Hassler on how to achieve additional efficiencies if NASA selects the SwRI proposal for the AIS instrument.

A focused group of Co-Investigators rounds out the capabilities of the AIA team. Their responsibilities are described in the following sections and in Appendix G1. The appendices also provide, among other things, a discussion of how we will comply with the U.S. export laws and regulations. We cannot envisage a combination of personnel and institutional capabilities better suited to providing the AIA aspects of the SDO and LWS missions.

E1 ORGANIZATIONAL STRUCTURE AND RESPONSIBILITIES

The AIA functional organization within Lockheed Martin is totally contained within the Space and Astrophysics Laboratory (LMSAL) portion of LM Advanced Technology Center (ATC). The ATC is a world-class research institute combining the best of university capabilities and industrial resources. Figure E-1 shows how the AIA program fits within the ATC. Of note for the SDO/LWS theme is that LMSAL is headed by Dr. D. Chenette, a recognized expert in the field of Magnetospheric and Heliospheric Physics and our sister department, the Space Sciences Laboratory, is headed by Dr. S. Fusilier another recognized expert in the field, and an AIA Co-I. His laboratory contains many well known ionospheric physicists. Both of these departments report to Dr. K. Strong, who has been a leader in the Solar Physics and Sun Earth Connection disciplines for many years.

Figure E-2 shows the AIA organizational structure. The ultimate responsibility for the AIA program resides with Dr. A. Title. He is the formal interface to NASA and to LM management. He is responsible for scientific leadership, management, instrumentation, E/PO, ground and flight operations, and data distribution, archiving, and analysis. Dr. Title is extremely well qualified for this position. He was the PI for SOUP, the LMSAL lead for MDI, and is the PI for TRACE and the US PI for Solar-B/FPP; and he has played a prominent role in advancing the concept of LWS and SDO. As the US PI on the FPP, he is intimately familiar with the optimal ways to synergize these two missions. Dr. Title is a Senior Fellow at the ATC and a member of Vice President A. Mika's staff. As such, his efforts are not charged to specific contracts.

Dr. Title is supported by a team of experienced personnel. L. Springer, as Program Manager, is responsible for day-to-day implementation of the program. He was the SXI PM during its

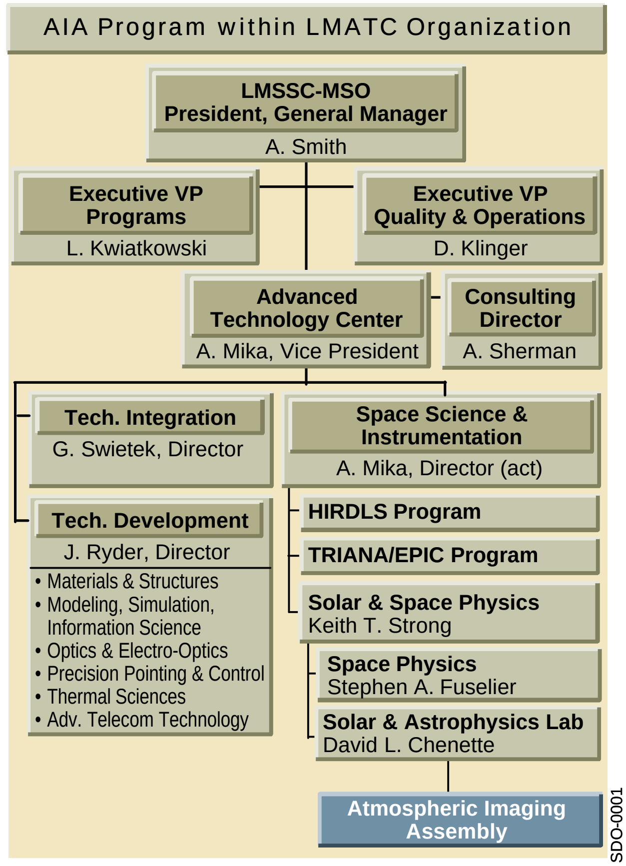

Fig. E-1. *AIA is an integral part of the LMSAL with management oversight by personnel with expertise in the Sun-Earth Connection discipline.*

early years and is presently PM for the LMSAL portion of SECCHI, a responsibility he will hand over after SDO begins. Prior to SXI, he

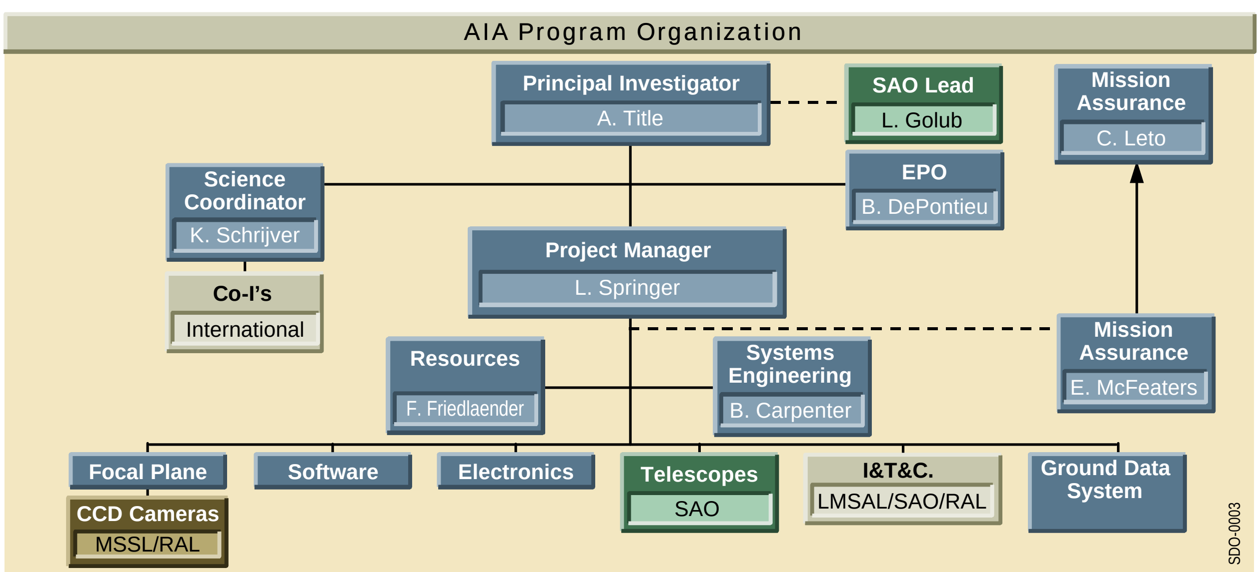

Fig. E-2. *The AIA organizational structure emphasizes that our major partners, SAO and the UK groups, are integrated members of the team; while reflecting the clear authority of the Principle Investigator and Program Manager.*

was the electronics lead on MDI. Mr. Springer will be supported by the leads for Mission Assurance, Resource Management, and Systems Engineering; all have worked together and with Mr. Springer on several similar programs. In particular, Mr. B. Carpenter was Chief Systems Engineer (CSE) on the SXI program during its conceptual and design phases and is now the CSE on SECCHI. He, like Springer, will transition from SECCHI to AIA as SECCHI goes from design to fabrication (CDR in November), being replaced by younger members of LMSAL.

Dr. K. Schrijver leads the scientific effort on AIA. He has functioned in this role on TRACE since launch, making the transition to AIA a natural one. He was a member of the SEC Roadmap Teams for 2000 and 2003 and is on the LWS Architecture Team, which defined the concept of LWS and how SDO fits within it.

Dr. L. Golub leads the activities at SAO. He functioned in this capacity on the TRACE collaboration, which is the forerunner for AIA. He has been a key individual on numerous past space missions beginning with Skylab, continuing to this day with the revolutionary TXI solar rocket program. As the US PI on the Solar-B/XRT, he is intimately familiar with the optimal ways to synergize these two missions. The day-to-day activities at SAO will be overseen by Dr. J. Bookbinder. This was true as well for the TRACE collaboration, again emphasizing that the working relations of these two major AIA partners have been well established and successful.

Table E-1 summarizes the roles and responsibilities of all AIA Co-Is, associate investigators (AIs), other key personnel, and their institutional affiliations.

Table E-1. *Key personnel roles & responsibilities*

Team Member	Role	Responsibilities
LMSAL		
A. Title	PI	Ultimate responsibility for AIA
D. Alexander	AI	Coronal modeling plans
M. Aschwanden	AI	3-D modeling plans
B. De Pontieu	Co-I	E/PO & coronal seismology plans
S. Fuselier	Co-I	Connections to geospace
N. Hurlburt	Co-I	Data systems lead & modeling
J. Lemen	Co-I	Instrumentation & science planning
T. Metcalf	Co-I	Magnetic phenomenon plans
N. Nitta	Co-I	Eruptive events plans
C. Schrijver	Co-I	Oversee all scientific efforts
R. Shine	Co-I	Operations lead
L. Springer	PM	Day to day program management
T. Tarbell	Co-I	Inter-experiment coordination
C. Wolfson	Co-I	Mgt. consultant & ops planner
J. Wuelser	Co-I	Instrumentation & flare plans
Smithsonian Astrophysical Observatory (SAO)		
L. Golub	Co-I	Responsible for SAO participation
J. Bookbinder	Co-I	SAO Program Manager
E. DeLuca	Co-I	Coronal seismology plans & E/PO
A. vanBallegooijen	Co-I	Theory planning
H. Warren	Co-I	Coronal heating irradiance plans
Montana State University (MSU)		
P. Martens	Co-I	Coronal heating & irradiance plans
D. McKenzie	Co-I	Science planning, sensitivity, E/PO
Stanford University		
R. Bush	Co-I	Data system & science planner
A. Kosovichev	Co-I	Science planner
D. Martinez-Galarce	AI	Coordinate with MSSTA
P. Scherrer	Co-I	Coordinate H(V)MI
National Solar Observatory (NSO)		
C. Keller	Co-I	Coordinate GB observatories
Goddard Space Flight Center (GSFC)		
J. Brosius	Co-I	Coordinate radio observatories
J. Gurman	Co-I	GSFC Lead & data systems
D. Rabin	AI	Science planning
Marshal Space Flight Center (MSFC)		
A. Gary	Co-I	Field modeling plans
Science Applications International Corporation (SAIC)		
Z. Mikic	Co-I	Field modeling plans
Southwestern Research Institute (SwRI)		
D. Hassler	Co-I	Coordinate AIS
Mullard Space Science Laboratory (MSSL)		
J. L. Culhane	Co-I	UK coordinator & science plans
L. Harra	Co-I	Solar activity plans
Rutherford Appleton Laboratory (RAL)		
A. Fludra	Co-I	Science planning
R. Harrison	Co-I	CME & spectral science
N. Waltham	Co-I	Camera design & implementation
St. Andrews University		
E. Priest	Co-I	Plasma physics plans
European Space Agency		
B. Fleck	Co-I	ILWS coordination
University of Copenhaegn		
Å. Nordlund	Co-I	Coronal theory plans
Royal Swedish Academy of Sciences		
G. Scharmer	Co-I	Coordinate GB observatories
Cambridge University		
N. Weiss	Co-I	Field flow modeling plans
Meudon		
P. Demoulin	Co-I	Field extrapolation plans

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E1.1 Smithsonian Astrophysical Observatory

Over the past three decades, SAO has been a major hardware contributor to nine key astronomy missions, including Einstein, ROSAT, AXAF (now Chandra), SWAS, TRACE, and

Solar-B. These state-of-the-art space flight hardware and support system efforts were extremely demanding in their need for in-depth program management capability. SAO's High Energy Astrophysics Division (HEAD) also has a major technical and subcontractor management monitoring role in support of the MSFC AXAF Project Office. HEAD has developed and implemented a range of policies, procedures and management controls which have established a proven, successful track record in the timely and cost-effective execution of space missions. When combined with SAO's experience in the science and engineering aspects of flight hardware similar to that for AIA, it is clear that SAO is a quality partner for teaming with LMSAL on this mission.

E1.2 UK Participants

Prof J. L. Culhane of the MSSL will coordinate the AIA efforts in the UK. He has participated in many NASA missions being the PI (or UK PI) on SMM/XRP, Spacelab-2/-CHASE, Yohkoh/BCS, and Solar-B/EIS. Prof. R. Harrison of the RAL will join Culhane in executing the UK hardware responsibilities. He is presently PI on SOHO/CDS and the UK PI on STEREO/HI.

The **MSSL** has been active in the Space Sciences for more than forty years and has provided instruments for more than thirty orbiting and interplanetary space missions including Yohkoh, SOHO and Solar-B. Instrument development work is undertaken either in house by teams of professional engineers or on contract to industry. There is a strong program management capability with Prof. A. Smith in overall charge. He will be responsible for procurement and testing of the CCDs, as is the case on the LMSAL SXI and FPP programs.

The **RAL** has also been active in experimental space science from the beginning of the space age with involvement in over 50 missions including AMPTE, ROSAT, HIRDLS, Yohkoh, and SOHO. Current missions at RAL include Solar-B and STEREO. Development of CCD cameras for all of the SECCHI instruments is being undertaken by Dr. N. Waltham. The same will be true for AIA, where the proposed cameras are modifications of the SECCHI cameras. The RAL has a unique capability for absolute calibration of EUV instruments. AIA will undergo end-to-end calibration there.

E2 MANAGEMENT IMPLEMENTATION

The management approach for AIA is one that has evolved over several decades of developing instruments as an integral part of conducting scientific investigations. Foundations of our approach are:

- Clearly stated and documented requirements that flow down from the measurements necessary to achieve the scientific goals.
- A program structure consistent with requirements, and resources allocated to the elements of that structure.
- Continual evaluation of the matching of the resources to the requirements and making adjustments as necessary to maximize the scientific return for resources expended.

This is done in an environment where scientists, engineers, technicians, and support personnel from not only LMSAL but from all involved institutions interact in an open and continuous manner. A series of very successful programs that have functioned in this manner validates our approach.

E2.1 Requirements Management and Tracking

The AIA instrument is designed to make the measurements required to accomplish the science objectives described in §C of the proposal. The flow from science objectives to top-level requirements that has begun with this proposal will be captured in an Instrument Performance Specification (IPS) document during Phase A of the program.

The IPS will be a living document, receiving modifications as the program evolves. In particular, as the program moves beyond Phase A, it will be expanded to include the requirements flow down to subsystems and assemblies. At these lower levels, the specifications are expanded to address not only performance but also the allocated resources (primarily mass and power) and the interfaces to other subsystems. The details of these interfaces are formally documented and controlled by Internal Interface Agreement documents. A set of Engineering Design Notes is created that contain the details of individual hardware and software items, including the motivation for the approach being implemented to achieve the required performance. Elements of AIA being developed by our SAO and UK partners are treated in a manner identical to those being developed at LMSAL. The ground data system requirements will be documented in a manner analogous to the instrumental requirements. Our experiences on prior programs have demonstrated the effectiveness of this approach wherein all members of the team work with documentation that clearly shows the paths being taken.

As the requirements and designs for subsystems and assemblies solidify, the methods for verifying performance are established and documented by the responsible engineers. These flow upward to form verification criteria for higher level elements, resulting in an Instrument Verification Plan. §C2.a.13 of this proposal presents a preliminary Verification Matrix.

E2.2 Communications, Meetings, Reviews

Continuous and open communications are inherent in our management approach. At LMSAL our scientists, engineers, technicians and support (finance, contracts, mission assurance) personnel all work in the same building and constantly interact on an informal basis. Topics can be immediately clarified by walking down the hall and talking with the appropriate person. In addition, everyone is tightly linked via e-mail and Web sites. This is especially helpful for keeping our partners at SAO and in the UK in the loop. A one-hour, all hands, weekly meeting rounds out our internal communications. As was the case on TRACE, SAO will participate in the weekly meeting by telephone or videophone. The latter was quite effective during the proposal preparation stage, using new facilities at both SAO and LMSAL. At the weekly meeting, each engineer reports on status, plans, and concerns. Focused meetings are then scheduled to resolve concerns or review designs in depth. We will have a separate weekly videoconference with our UK partners. The results of the focused meetings, the weekly all-hands meeting, and the UK videoconference are posted on the Web to keep everyone up-to-date. Routine (usually weekly) telecons are held with all major subcontractors/vendors to recognize and solve problems early and (especially) to include them as an integral part of the AIA team. Periodic (approximately bi-monthly) visits are made to the subcontractors/vendors location for the same reasons.

A narrative monthly progress report will be provided to NASA, all team members, and LMATC upper management. Besides providing program status, these reports discuss problem/risk areas, proposed solutions, and specific activities planned for the next month. Information from our UK and SAO partners is included in a manner equivalent to that from the LMSAL subsystem leads. The reports are posted on the Web for archival use. The AIA program status will also be presented to LMATC upper management bi-monthly. These reviews provide useful input from experienced personnel not directly involved in the program. They also keep program visibility high and enable us to receive assistance from upper management in a timely fashion when needed.

We anticipate having weekly telecons with the GSFC Project management team, a process that worked extremely well on the TRACE program. In addition, we anticipate participating in routine telecons with all SDO groups, in a series of engineering peer reviews, and in the normal series of formal reviews (Conceptual, Preliminary Design, Critical Design, Pre-Environmental, Pre-Ship, Launch Readiness, etc.). Co-Investigator and community-wide science meetings at approximately 6-month intervals complete the review process. Often, some of the most critical and helpful comments come from our scientific peers at these meetings. During Phase A we will aggressively work to ensure that all SDO instruments operate as a system.

E2.2.1 Decision Making Process

Although communications are open, decisions are made in a structured manner. We follow the lines of authority shown in the organizational charts and the specifics, including the involvement of NASA, called out in the Product Assurance Implementation Plan (PAIP), SOW, and contract. The decisions are immediately documented in meeting summary minutes and other memos and then incorporated into the appropriate documents, like the IPS or contract.

E2.3 Cost and Schedule Control

The keys to controlling cost and schedule include (1) having a clearly defined set of requirements/tasks, (2) making accurate original estimates, (3) continual review of all requirements and interfaces, (4) making early and firm decisions based on these reviews, (5) replanning as the program evolves, (6) allocating reserves as appropriate, and (7) using management tools that provide clear visibility into the status of the program. These features have been fine tuned on prior successful programs of this nature (Table E-2) with the constant realization that the available resources only allow a task to be completed “good enough” rather than better or best.

During the preparation of this proposal, the program was defined by scientists and engineers in a coordinated manner and documented in a detailed WBS, schedule, and cost estimations. These will be refined during Phase A of the program, resulting in a formal proposal to NASA, and kept current thereafter. At the start of the program a Scope and Detail Work Order is issued to authorize the expenditure of funds. It includes a list of charge numbers that bears a one-to-one relationship to the WBS. Weekly reports show every hour and every dollar spent by WBS element and the personnel who worked those hours, providing the program office with excellent visibility into the program. Monthly and quarterly financial reports will be provided to NASA in the standard 533M and 533Q formats, and the schedule will be provided monthly using Microsoft Project.

Table E-2. *AIA will continue the excellent performance record of previous and present programs.*

Recent NASA Programs at LMSAL	
SXT	• First CCDs flown on a solar satellite; functioned 10 years on orbit until the satellite was lost • Pioneered SolarSoft for joint analysis of data from different instruments
MDI	• First instrument delivered to ESA for the SOHO mission; on orbit for >5 years; survived severe cold when satellite was lost for many weeks • Within schedule and budget; after accounting for reserves
TRACE	• Prime example of faster/cheaper/better; on orbit for >4 years • GSFC returned $9M of unspent funds to NASA Headquarters
SXI	• One flight model delivered within schedule and budget and the second in test • Average incentive feed of >91%

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We have already developed a detailed schedule. The multilayer coated mirrors were on the critical path so we are now ordering the glass blanks during Phase A of the program to alleviate pressure in this area. The detailed schedule will be revised during Phase A of the program with each responsible engineer creating his or her subsystem schedule, iterating it with the PM, and “signing up to it.” These schedules, with emphasis on near term milestones, are statused at the weekly program meeting and updated with the PM and Resource Manager monthly or more frequently as needed.

E2.4 Management of Major Partners

The key feature in managing our two major partners is that both they and we feel they are team members, not just subcontractors or hardware providers. This relationship with SAO

SAO was solidly established during the execution of the successful TRACE program and continues with the XRT program; both efforts involve not only the same organizations at SAO and LMATC but also most of the same key individuals. The approach was validated when at the beginning of the MO&DA portion of the TRACE mission, SAO's expenditures were 1.8% below their contract value. Further validation comes from noting that the SAO group is presently on schedule and 13% under budget on the XRT program. Continual visibility into all SAO activities (and vice versa) will be an ongoing component of this partnership.

Our partners in the UK receive no financial support from the US, making this a different formal relationship than the subcontract with SAO. However, there is a Letter of Agreement between the UK and US governments and we have worked with these same groups and individuals for decades; Culhane was PI of our OSO-8 instrument when he was a member of our laboratory in the early 70's. Again, constant communication by all partners is key to our success. If for some reason PPARC could not fund the UK efforts we have complete in-house capability to produce the camera systems. They would be an extension of the CCD cameras we produced for MDI, TRACE, SXI, and Solar-B. The CCDs are even from the same vendor as those for SXI and Solar-B.

We have deliberately not included other groups in AIA hardware roles. The interface and management issues that go along with such inclusion do not make it beneficial unless the contribution is quite major, with this being even more true with foreign involvements than domestic.

E2.5 Mission Assurance (MA)

The AIA mission assurance function is comprised of quality assurance (hardware and software), systems safety, reliability, EEE parts control, materials and processes, and contamination control. These combined functions work in concert to ensure that the delivered products meet all requirements with the highest practical reliability. The AIA mission assurance manager, who has a separate reporting chain in the management structure thereby ensuring independent oversight of these critical program aspects, manages these functions. An AIA mission assurance plan, hereafter called the PAIP will be written during Phase A in accordance with the SDO specific Instrument Mission Assurance Requirements (IMAR) document.

LMSAL's mission assurance approach ensures that reliability and performance requirements are met throughout the program. A structured system of checks and balances coupled with key inspection points provides the required control. LMSAL mission assurance personnel instill discipline throughout the design and build cycle. They are key members of the AIA team and the design process. A separate LM mission success organization reviews the program at critical points. The AIA MA program contains the following elements, each of which will be detailed in the PAIP.

A **quality system** that is certified to the ISO-9001-1994 standard by the British Standards Institute (BSI). Continual improvement is implemented and BSI performs re-certification every 6 months. LM is currently moving towards the newest ISO-9001-2000 standard. Hardware and software quality engineering plays an integral role in all program aspects including the review of all engineering drawings, code design and analysis, shop paper, procurement orders, test procedures and documentation. AIA software will be developed in accordance with processes based on the LM Standard Software Process (SSP) and adapted to AIA's specific needs. The development approach will be documented in a Software Management Plan. The software quality engineer will monitor the software development progress to ensure adherence to the AIA software processes.

A **quality inspection function** is staffed with trained and certified inspection personnel who have significant space flight hardware experience. The inspection aspect of the program not only consists of those detailed inspections called out by the shop paper or receiving inspection, but also comprises area surveillance.

A **systems safety engineer** is involved with all aspects of the design, handling equipment, and GSE reviewing them for safety issues/concerns. In the event that hazards are identified, they are put into a formal hazards analysis format and presented at all major reviews.

A **reliability engineer** is involved in the program at the outset to ensure that the developed designs comply with of all AIA reliability requirements. This allows reliability driven impacts to be accommodated with minimal cost and schedule impact to the program.

An **EEE parts engineer** works with the design engineering team, including the reliability engineer, to ensure that all EEE parts requirements are met. The parts engineer manages all aspects of EEE parts program including the generation of the EEE parts list, conducting PCB (parts control board) meetings, issuing PCB minutes, performing GIDEP and internal alert searches, directing the screening of parts, and performing failure analysis on any failed parts.

An **M&P (materials and process) engineer** ensures that those materials and processes selected are space qualified and meet the AIA requirements. A materials and process list developed during the design phase of the program identifies the material used, the quantity, and the assembly/drawing number.

A **contamination control engineer** ensures that all AIA and SDO contamination control and cleanliness requirements are identified and met by working closely with the design engineering team, including the M&P engineer. An AIA Contamination Control Plan will be written during Phase A of the program.

E2.6 Risk Management Plan

The AIA risk management approach is modeled after that established for our Solar-B programs with refinements from the SECCHI program. By conceiving an instrument with extensive heritage and little new technology, we begin the program with minimal intrinsic risk. This will be further aided by beginning to work quite early on elements that are likely to consume the most time. In particular the mirror blanks, which are not very expensive, will be ordered during Phase A of the program and our UK partners will move rapidly into the CCD and camera development areas as direct extensions of existing programs. All members of the AIA team will be made fully aware that early identification of possible risks is an important component of their responsibilities.

The Chief Systems Engineer, working with the relevant team members, is responsible for categorizing the risks following a procedure that assigns a probability of occurrence (high, medium, or low) and impact (high or low). All significant risks are thus documented. Those with medium impact and high probability are tracked weekly and any risk with high impact and high probability receives a formal abatement plan in addition to the tracking. The abatement plan includes closure criteria, op-

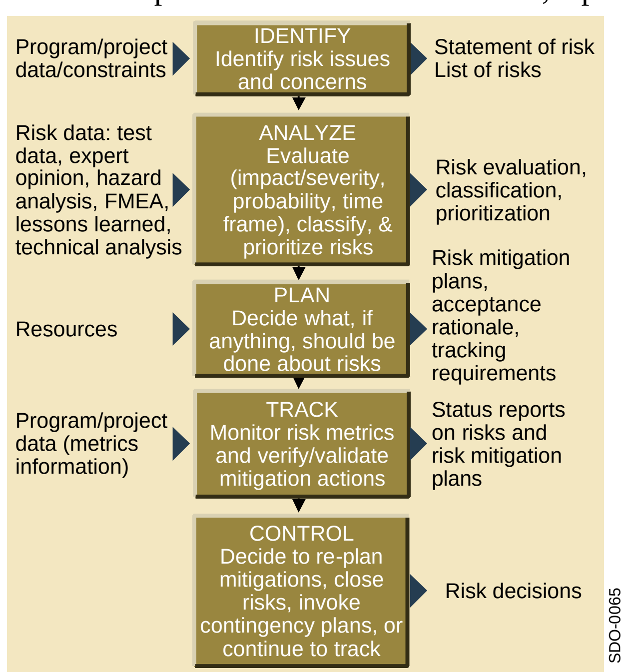

Fig. E-3. *Risk mitigation is a continuous process throughout the product lifecycle with the results integrated into the AIA development program.*

tional paths, and anticipated cost, schedule and performance hits. Reserves will be allocated as warranted to accomplish abatement, with NASA immediately involved should the available reserves and closure criteria be incompatible with the existing contract. Figure E-3 demonstrates our process.

A Risk Management Plan that complies with §4.2 of NPG 7120.5A, as well as with the intent of LMMS Practices P3.1.2, will be formulated during Phase A of the program, as will the initial risk matrix. The risk matrix, which includes planned mitigation measures, will be part of every monthly progress report, enabling the evolution of the risks to be easily tracked. It will also be presented at all major reviews.

E2.6.1 Descope Plan

Any descopes to the AIA instrument/program would result in corresponding descopes in the scientific investigation as compared to both that in our proposal and that described in the AO. However, the following items could be considered if a lesser investigation is the only one that can be accomplished within the available resources. Table E-3 shows resource decreases for each descope as a function of when the descope decision is made.

1) Reduce the number of CCDs that can be read out simultaneously from 4 to 2, which would correspondingly decrease observing flexibility resulting in either a slower cadence or decreased signal in the weaker channels. Such a descope would eliminate two electronic boards.
2) Delete the end-to-end instrument calibration at RAL, resulting in a less quantitative ability to deal with the data.
3) Eliminate the aperture selector from the only telescope that presently contains it, thereby either losing one of the EUV channels or redistributing the channels so that they all remain but the analysis of one is complicated by leakage from its partner. This decreases the capability to deal with the multi-thermal plasma.

Table E-3. *Descope results if elected at SRR, PDR, or CDR.*

Item	Mass (kg)			Power (W)			Schedule (wk)			Cost ($K)		
	SR	PD	CD	SR	PD	CD	SR	PD	CD	SR	PD	CD
Only two simultaneous CCD readouts	1.0	1.0	0.5	6	6	6	0	0	0	350	315	175
No calibration at RAL	0	0	0	0	0	0	6	6	6	375	375	325
Delete aperture selector	2.0	1.0	0.5	1	1	1	0	0	0	600	550	200
Delete one telescope	12	10	8	10	10	8	6	6	3	1800	1000	600

SR= systems requirements review; PD= preliminary design review; CD= critical design review

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4) Eliminate an entire telescope, most likely the one with the 304Å and 132 Å channels, thereby more strongly decreasing the capability to deal with the multi-thermal plasma. This is listed instead of the prior item, not in addition.

E2.7 Schedule

Figure E-4 shows the top-level program schedule including major reviews and hardware deliveries. The total time span is consistent with our experiences on prior programs. The expenditure of nearly 6% of the contract funds during Phase A of the program will enable us to ramp up and move out immediately after contract award in order to position ourselves for meeting the remainder of the schedule. Our experience on TRACE provides us with confidence that with the spacecraft being provided by GSFC, we will be able to establish detailed S/C interfaces and resource allocations rapidly, a necessary feature to minimizing schedule and cost risk.

E2.8 Work Breakdown Structure

A top-level WBS is shown in Table E-4. It reflects the efforts to be performed and is the basis for managing cost and schedule. As a living document, it will change modestly as the program evolves.

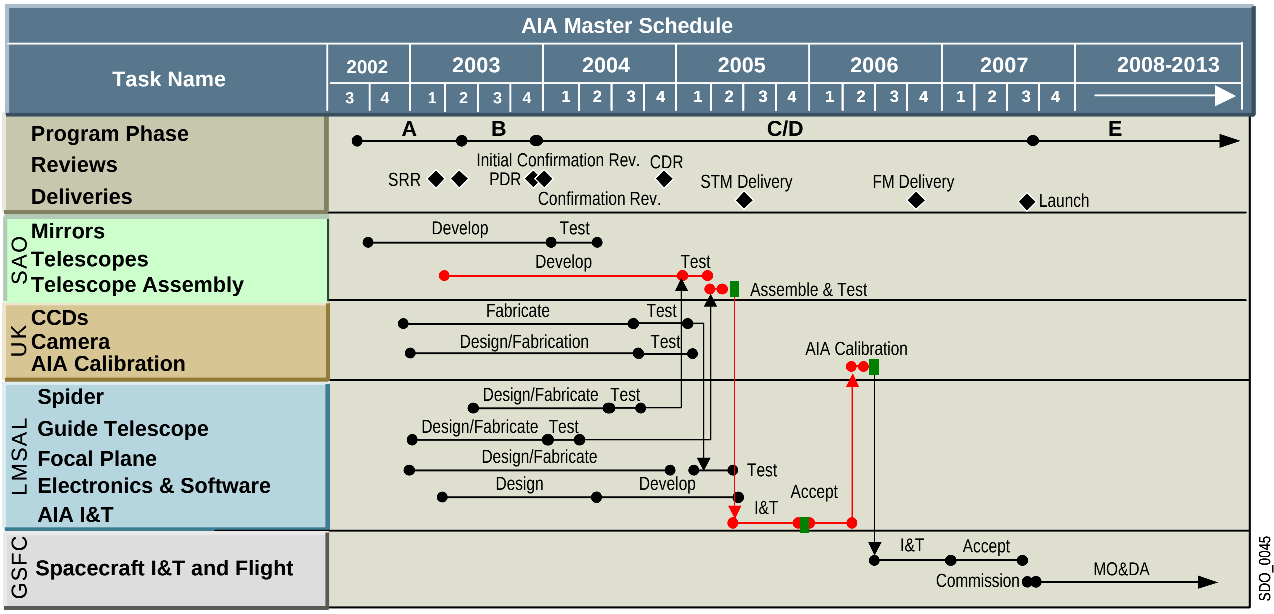

Figure E-4. The top-level AIA schedule shows key links, major reviews, hardware deliveries, and the location of the activities. EPO activities begin in Phase A and continue throughout the program. Funded reserves shown in green; critical path shown in red.

E2.9 Approaches for Combining with the HMI and/or AIS Programs

Stanford University and LMSAL are partners in proposing an investigation to accomplish the goals of the HVMI portions of the SDO mission, with Prof. P. Scherrer as the Principal Investigator. The HMI flight instrumentation, if selected, will be developed entirely at LMSAL under the direction of Dr. A. Title with the integral involvement of Stanford personnel. Scherrer and others from Stanford are Co-Is on AIA and Title and others from LMSAL are Co-Is on HMI. The Stanford-Lockheed Institute for Space Research coordinates these activities. This is the identical approach that was used on the successful MDI program. If both AIA and HMI are selected, LMSAL will blend the two programs together to eliminate duplication of efforts in many instrumental (see §C2.a.15), ground data system, and programmatic areas.

Although a combined AIA-HMI program is a major undertaking, we are extremely well positioned to accomplish it. Our, as well as SAO's, Solar-B efforts have crossed over from design to implementation and will be moving into the I&T phase shortly after SDO begins. The first flight unit of SXI has been delivered and the second is in test, while the (much smaller at LMSAL) SECCHI program will have its CDR this November. Thus, the key personnel who are needed to efficiently initiate the SDO programs will be available immediately. The phasing for then building up the SDO HMI-AIA teams as these other programs decrease in personnel and their talent needs change could not be better. In addition, most of the areas of AIA that are not duplicated in HMI are the responsibility of SAO, so it is "easy" for LMSAL to perform on AIA if already developing HMI.

During the proposal stage, we have had discussions with Dr. D. Hassler of SwRI, who is proposing an AIS investigation, concerning possible collaborative developments. Hassler is a Co-I on AIA and Schrijver is a Co-I on the AIS proposal. If it is selected, we will work together during Phase A to establish (and propose) the overlaps we determine to be programmatically and scientifically beneficial.

Table E-4. *Our top-level WBS clarifies how tasks fit within the total program.*

AIA WBS			
1.0	**Instrument Development**		
1.1	Program Management		
1.2	Systems Engineering		
1.3	Mission Assurance		
1.4	Instrument Subsystem		
	1.4.1	Telescope subsystem (4) (SAO)	
		1.4.1.1	Telescope management & SE
		1.4.1.2	STM & brassboards
		1.4.1.3	GSE
		1.4.1.4	Flight model
		1.4.1.5	Integration, test & verification
		1.4.1.6	Telescope mission assurance
	1.4.2	Camera subsystem (4) (UK)	
		1.4.2.1	CCDs (MSSL/Marconi)
		1.4.2.2	Camera electronics (RAL)
		1.4.2.3	Camera GSE
	1.4.3	Focal plane subsystem (4)	
		1.4.3.1	Structure
		1.4.3.2	Header
		1.4.3.3	Shutter
		1.4.3.4	Filterwheel
		1.4.3.5	Focal plane filters
		1.4.3.6	Internal cabling
		1.4.3.7	Focal plane I&T
	1.4.4	Secondary spider subsystem (4)	
		1.4.4.1	Structure
		1.4.4.2	Aperture selector (1)
		1.4.4.3	PZT assembly
		1.4.4.4	Strain gage preamp
		1.4.4.5	Focus mechanism
		1.4.4.6	Calibration source
		1.4.4.7	Internal cabling
		1.4.4.8	Spider subsystem I&T
	1.4.5	Electronics box	
	1.4.6	Intra-instrument harness	
1.5	Guide telescope		
	1.5.1	Optics & filter	
	1.5.2	Structure	
	1.5.3	Limb sensor	
	1.5.4	Preamp	
	1.5.5	Thermal	
	1.5.6	GT I&T	
1.6	Software (flight and GSE)		
1.7	Ground support equipment		
1.8	Instrument I&T and calibration		
1.9	Spacecraft I&T support (LMSAL & SAO)		
1.10	Launch support (LMSAL & SAO)		
1.11	Pre-launch science ops/DA/algorithm develop (all)		
1.12	Special launch service costs – N/A		
1.13	Special ground data systems costs – N/A		
1.14	Reserves (LMSAL & SAO)		
2.0	**Science Ops & Data Analysis**		
2.1	Post launch science operations (all)		
2.2	Post launch data analysis (all)		
3.0	**Education and Public Outreach**		
3.1	Pre-launch E/PO (all)		
3.2	Post launch E/PO (all)		

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F COST ESTIMATING METHODOLOGY AND COSTS

The estimated costs for the AIA program were obtained using the same approach that we have used on a long series of prior similar programs. The adjective “similar” is important, in that like AIA they were PI-led science investigations that involved producing an instrument to make the required measurements, and all of the key personnel involved in AIA were involved in several of these programs. The approach is to do a modified bottoms-up costing of each task by the person who will be responsible for carrying out the task. These are reviewed by the management team (PI, PM, and Resource Manager) to eliminate duplication of effort, rationalize the task plans, and uncover areas that were overlooked, and then revised accordingly. The agreement between proposed and actual costs of programs such as TRACE, MDI, SXT, and SXI provide confidence in our approach.

The approach is described as “modified bottoms-up” because heavy reliance has also been placed on the actual costs of analogous tasks on similar programs. This is especially relevant since AIA is an evolution of TRACE, a program that is universally recognized as one of the best examples of the faster, cheaper, better paradigm. A cost model was not directly used, nor have we used one on prior programs. However, a sanity check using an LMATC model of costs as a function of program type, heritage, and complexity supports the estimate. The cost estimates will be iterated and refined during Phase A resulting in a formal cost proposal for Phases B-E. Firm-fixed prices are provided for Phase A and the Bridge Phase option. The remainder of this section describes the fundamental assumptions that went into the costing, elaborates on the basis for estimating the efforts, and describes the cost reductions associated with possible descopes as well as those that can be achieved by combining the AIA and HMI programs.

F1 TOP-LEVEL ASSUMPTIONS

We have had to make some top-level assumptions in estimating the costs of the AIA program and have done so with the knowledge that SDO is a cost constrained program. These assumptions include, but are not limited to:

- GSFC, as the spacecraft provider, will create and maintain the AIA-S/C ICD, using our inputs and reviews as appropriate.
- The spacecraft will have a contamination control program appropriate for a payload that includes EUV imaging – the TRACE program being a good example of an in-house GSFC spacecraft for which this was true.
- A class-2 EEE parts program will be implemented, as was clarified in the FAQ portion of the AO on the Web.
- A formal EVM system will not be required of PI-led investigations, including those that produce instrumentation.
- The schedule in the AO will be held to, with a funding profile that enable this.
- The STM that is delivered to the S/C will not contain functioning optics, electronics, or mechanisms. It will be delivered in June 2006; the AO did not specify a date.
- A specific SDO IMAR, as contrasted to the draft LWS MAR that applies to all elements of LWS including spacecrafts, will be provided during Phase A.

F2 BASIS OF COST ESTIMATES

The following narrative briefly describes the basis for estimating the proposed program costs.

F2.1 Program Management

Program management involves overseeing the entire program on a day-to-day basis including managing cost and schedule resources as well as risks. It also includes configuration management activities and all travel costs. Our estimate for these efforts is based on the actual costs for similar prior programs and roughly equates to an average EP level during Phases A, B-D, and E of 1.9, 2.3, and 0.2 respectively. It does not include the SAO management costs; these are captured in WBS 1.4.1.

F2.2 Systems Engineering

Systems engineering includes defining interfaces (internal and external), analysis activities (mechanical and thermal math models, error budgets, etc.), reviews (internal, peer, Project), requirements specifications and verification, and other general systems engineering activities. Our estimate for these efforts is based on the actual costs for similar prior programs and roughly equates to an average EP level during Phases A and B-D of 1.0 and 1.5. Again, the equivalent SAO costs are captured in WBS 1.4.1.

F2.3 Mission Assurance

Mission Assurance includes the normal disciplines of safety, reliability, and quality plus parts engineering, materials and processes activities, and contamination control. It also includes software and product assurance activities and presenting the program at LM mission success reviews. Due to the increased emphasis on MA by NASA we have based this estimate on our SXI experience rather than on TRACE and MDI. This amounts to about 20% of the technical hours.

F2.4 Instrumentation

Instrumentation, which is the largest cost element at this level of the WBS, is further subdivided into six pieces, each of which is briefly discussed below.

Telescope subsystems, a responsibility of SAO with LMSAL providing the secondary spider subsystem, are a major element within AIA. SAO estimated these costs with the same modified bottoms up approach that was used by LMSAL. These costs, at both the system and subsystem level, were then compared with the costs for similar work on a variety of space programs, including AXAF/HRC, XRT, and TRACE. Cost models were not used. Vendor quotes were obtained for all major hardware and service procurements; with the quotes being based on RFIs that contained preliminary technical specifications and SOWs. SAO management, systems engineering, and mission assurance costs are contained within this element, as is the cost of the deliverable STM. Costs for SAO participation in E/PO, I&T, operations, and science (both pre-launch preparations and post launch) are captured in the corresponding categories.

Camera subsystems are provided by the United Kingdom under a no exchange of funds arrangement. They include characterized CCDs as well as the camera electronics. The estimated value of this contribution is shown in Cost Table B-2. Our UK colleagues made this estimate based on their experiences on prior programs, especially STEREO and Solar-B.

Focal plane subsystems include the CCD cooling and shielding systems, filter wheels, shutters, and the effort of integrating these items with the UK-provided camera subsystems. The overall mechanical/thermal approach is an evolution of that being used on Solar-B and estimated accordingly; only modest NRE is required. Similarly, the focal plane shutters and filterwheels (including the filters) have extensive heritage at LMSAL. They are simply scaled version of evolutionary preferred designs, so their costs are well understood. Life testing for each type of mechanism that is used extensively is included.

The **secondary spider subsystem** includes the focus mechanisms, aperture selector (where needed), and the active mirrors. The focus mechanism and active mirrors are direct evolutions from TRACE and the aperture selector uses a hollow core motor similar to that used on the last five of our programs. As such, their costs and the costs of integrating the spider are well established.

The **electronics subsystem** contains all of the AIA electronics except the camera electronics. The heart of the system is a RAD 750 computer purchased from BAE. We received a quote from BAE for this proposal. The remaining electronics are all very similar to electronics we have developed previously. In fact, the mechanism controller boards that are being used on Solar-B and SECCHI will be used on AIA to minimize costs in these areas. From recent and similar programs we have developed equations for estimating electronics development costs based on the number of boards, their complexity, and the number of FPGA designs that are required. Several of the (~14) FPGA designs are slight modifications of designs being used on Solar-B, and this has been taken into account.

Intra-instrument harness costs were estimated based on our experiences in prior programs. It is assumed that GSFC will provide the harness from the S/C to the electronics box and that LMSAL will supply the harness between the electronics box and the telescope assembly.

F2.5 Guide Telescope

A guide telescope is included as an integral element of AIA because it provides the error signals for the telescopes image stabilization systems. It also provides the fine pointing error signal for the spacecraft. The approach is that pioneered on TRACE although simplified because the ability to point a small field of view anywhere on the solar disk is not required. This is also the case for the GT we are providing on STEREO. The methodology for using the GT error signals in the ISS control loop is identical to how it is done on TRACE. With all of this heritage we are able to very accurately predict the costs for AIA. As a cost saving, we will use the same optical/mechanical packaging as on SECCHI.

F2.6 Software

Software will be quite simple on AIA due to the conveniences (and constraints) of the very high data rate, full disk imaging, and synoptic nature of the science. There will be no onboard image processing. Data compression is done in hardware “on the fly” as is the automatic exposure control and event flag generation. Thus, the software only controls the observing program, labels the images, controls the down link, controls the thermal systems, and provides typical housekeeping information with a modest ability to react to out-of-nominal conditions. Our experience with similar software systems on prior programs yields good estimates for both of these efforts. GSE software is included in this WBS element.

F2.7 Ground Support Equipment

Ground support equipment contains optical, mechanical, and electrical elements as well as a software development system. The optical GSE includes a Stimulus Telescope for activating both the GT and the EUV telescopes themselves (when a front filter is removed). All of the items are basically identical to those developed for TRACE and SECCHI, so their costs are well understood.

F2.8-10 Integration & Test Activities

Integration and test activities at LMSAL, GSFC, and the launch site assume a level of effort that is based on our prior program experiences, TRACE being a prime model since it was a GSFC in-house spacecraft like SDO. Test facility costs are well known from other programs where the baseline is to perform acoustics at the LM Sunnyvale facility, thermal balance/vacuum in our LMSAL building, and EMI and vibration at the facilities of outside vendors. This is the most cost effective approach based on our past experience, and the costs are well understood. System level calibration will be performed at RAL as one of the UK contributed items; the financial value of this contribution is included in Cost Table B-2. Our partners at GSFC will participate in the I&T activities, taking a coordination lead for S/C I&T, and these costs are also in Cost Table B-2.

F2.11 AIA Pre-launch Science Support

The tight budget constraints of the SDO mission mean that an adequate scientific program cannot be funded entirely inside the AIA budget. Funds will primarily be expended on tasks that directly relate to producing the instrumentation and to being prepared to handle the large data stream when it begins to flow. At LMSAL the effort is approximately 5 man years to set up the data handling system and SOC and a similar amount to scientifically guide the instrument development. SAO has a relatively similar effort in scientific instrumentation guidance. Designated coordinators will be funded to organize the scientific community into task areas important for AIA. Individual science projects will be funded from other sources as indicated in §C1. Efforts by our foreign colleagues, at no cost to the NASA, are also essential. As little computer hardware as practical is procured (~$400K) under this effort, plus LM will provide computer equipment (~$500K) as fixed assets. These estimates are based on industrial roadmaps for future products. LM will also fund an independent research program (~$300K/year) to develop advanced image display and analysis tools.

F2.12-13 Special Launch Services/ Special Ground Data Systems

We have identified no costs for special launch services or for special ground data systems.

F2.14 Financial Reserves

After estimating the entire program costs both SAO and LMSAL revisited the tasks to determine what level of financial reserves would be appropriate for the instrument development portion of the program, Phases B-D. The extensive heritage of the instrumentation resulted in rather modest reserves to cover the surprises that seem to always occur no matter how well things are understood. The result is a reserve of $5,060K or 11% of the Phase B-D costs. SAO has been apportioned $1,857K of this, with $1M being targeted at obtaining the coated optics since history suggests uncertainty in this area.

F2.15. Post-launch Ops/Data Analysis Costs

The activities covered here are primarily those that are required to keep AIA operating in a safe and scientifically productive manner, to collect the large volume of resultant data, and to make these data available in a useful format for scientists, the space weather community and the general public. We will have a minimal science team to aid in the development of procedures for the analysis of the SDO mission data and discovery of new solar phenomena. Part of their task will be to aid users of AIA data and support the efforts of groups developing predictive tools. We will apply for additional support to conduct science programs and to aid in developing tools useful to the user community. Computer system procurements of ~$400K, included in this phase of the program, are projected to be adequate based on a conservative extrapolation of the industrial roadmap beyond 2007.

F2.16 Education and Public Outreach

The cost of the E/PO program amounts to a little over 1% of the total program costs with the tasks being distributed between LMSAL, SAO, and the combined efforts of two of our Co-I institutions – MSU and Stanford University (see §D). A much more desirable E/PO program could be achieved with a larger budget. During Phase A we will define an enhanced program and propose it for funds that would come from a higher-level LWS source rather than from SDO directly, as described in the AO and related materials.

F3 DESCOPE CONSIDERATIONS

Four possible descopes were described in §E2.6.1. The financial impacts, if executed early in the program, are estimated to be:

- $350K by reducing the number of CCDs reading out simultaneously from 4 to 2
- $375K by deleting calibration at RAL
- $600K by eliminating the aperture selector from the one telescope that needs it
- $2,000K by eliminating an entire telescope rather than one aperture selector

F4 AIA WITHOUT GUIDE TELESCOPE

The AO requests a stand-alone GT cost as well as the cost of an AIA without the GT. This is difficult since the GT not only provides the signals for fine pointing the spacecraft but those for the AIA ISSs and thus is integral to the software and hardware of AIA. A very rough estimate is that a stand-alone GT would cost $2.8M. However, should our AIA not be selected, we highly recommend that that GT be provided as part of the instrument. Conversely, although we consider it impractical, it is feasible that the GT be developed elsewhere and provide error signals for the AIA image stabilization systems. The AIA hardware cost would then decrease by about $300K but the additional costs of executing this complicated interface would surely exceed this amount.

F5 AIA/HMI COMBINED (&/or AIS)

Significant cost (and risk) savings will result if this AIA proposal and the Stanford HMI proposal are both selected. This is because LMSAL will develop all of the HMI instrumentation and much of the AIA instrumentation, including all of the elements that can be duplicated and/or shared between the two programs. The technical aspects of the arrangement are briefly described in §C2.a.15 and the programmatic aspects are addressed in §E2.9.

The estimated cost saving is $16.4M, of which $14.6M is prior to Phase E of the program. Cost Table B-4 provides a breakdown of these savings in a format similar to that of the standard tables, but condensed for ease of reading.

There will also be cost savings if the SwRI AIS proposal is selected along with this AIA proposal and/or the Stanford HMI proposal. The concepts are briefly touched upon in §C2.a.15 but have not matured enough to enable us to present a similar table of specific savings.

F6 AIA COST TABLES

Table B-2: Total Investigation Cost Funding Profile Page 1 of 2

(Costs by FY in real-year dollars, totals in real-year dollars (RYK$ and FY2002 K$)

Instrument: Atmospheric Imaging Assembly (AIA)

Item	FY02	FY03	FY04	FY05	FY06	FY07	FY08-13*	Total (RY $)	Total (FY02$)
NASA Cost									
Phase A	164	2,843						3,007	2,952
Phase B/C/D (includes Bridge Phase)									
WBS 1.0 Instrument Development		4,840	17,444	14,180	5,536	3,842		45,842	42,933
WBS 1.1 Program Management		378	1,162	1,024	701	501		3,766	3,503
WBS 1.2 Systems Engineering		388	954	631	440	44		2,457	2,294
WBS 1.3 Mission Assurance		214	884	705	459	81		2,343	2,175
WBS 1.4 Instrument Subsystem		2,969	10,224	7,852	1,459	734		23,238	21,905
WBS 1.4.1 Telescope subsystem (4) (SAO)†		1,995	6,436	4,561	1,459	734		15,185	14,174
WBS 1.4.2 Camera subsystem (4) (UK)		0	0	0	0	0		0	0
WBS 1.4.3 Focal plane subsystem (4)		263	458	591	0	0		1,312	1,254
WBS 1.4.4 Secondary spider subsystem (4)		215	800	505	0	0		1,520	1,444
WBS 1.4.5 Electronics box		496	2,425	2,156	0	0		5,077	4,898
WBS 1.4.6 Intra-instrument harness		0	105	39	0	0		144	135
WBS 1.5 Guide telescope		22	187	202	0	0		411	390
WBS 1.6 Software (flight and GSE)		430	1,098	518	0	0		2,046	1,934
WBS 1.7 Ground support equipment		74	372	171	140	12		769	742
WBS 1.8 Instrument and calibration		0	127	457	889	48		1,521	1,379
WBS 1.9 Spacecraft I&T support (LMSAL & SAO)		0	0	0	275	423		698	615
WBS 1.10 Launch support (LMSAL & SAO)		0	0	0	0	167		167	146
WBS 1.11 Pre-launch science ops/DA/algorithm dev.		46	411	479	544	1,359		2,839	2,634
WBS 1.12 Special launch service costs (N/A)									
WBS 1.13 Special ground data systems costs (N/A)									
WBS 1.14 Reserves (LMSAL &SAO)		319	2,025	2,141	629	473		5,587	5,216
Phase E:									
WBS 2.0 Science Ops & Data Analysis						55	11,942	11,997	9,759
WBS 2.1 Post launch science operations (all)						46	7,961	8,007	6,513
WBS 2.2 Post launch data analysis (all)						9	3,981	3,990	3,246
E/PO:									
WBS 3.0 Education and Public Outreach		77	100	156	105	125	355	919	812
WBS 3.1 Pre-launch E/PO (all)		77	100	156	105	125	0	563	522
WBS 3.2 Post launch E/PO (all)		0	0	0	0	0	355	356	290
Total NASA External Costs	**164**	**7,760**	**17,544**	**14,336**	**5,641**	**4,022**	**12,298**	**61,765**	**56,456**
GSFC Costs	0	10	10	60	145	70	60	355	310
Total NASA Cost	**164**	**7,770**	**17,554**	**14,396**	**5,786**	**4,092**	**12,358**	**62,120**	**56,766**
Contributions									
WBS 1.0 UK Contribution		740	3,080	2,900	900	1,120	5,000	13,740	11,979
WBS 1.1 Hardware, I&T and calibration		600	2,800	2,500	340	280		6,520	6,106
WBS 1.2 Science operations & exploitation		140	280	400	560	840	5,000	7,220	5,873
WBS 2.0 LM Contribution	503	600	347	350	700	TBD	TBD	>2,500	2,335
WBS 2.1 Fixed Assets	203	300	47	50	400	TBD	TBD	>1,000	940
WBS 2.2 Directed IR	300	300	300	300	300	TBD	TBD	>1,500	1,395
Total Contributions	**503**	**1,340**	**3,427**	**3,250**	**1,600**	**1,120**	**5,000**	**>16,240**	**14,314**
Total Investment Cost								**78,360**	**71,080**

* Yearly information for FY08-FY13 is on sheet 2 of 2; summary information is presented on page 1 of 2.
† WBS 1.4.1 includes SAO management, systems engineering, and mission assurance.

Table B-2: Total Investigation Cost Funding Profile Page 2 of 2

(Costs by FY in real-year dollars, totals in real-year dollars (RYK$ and FY2002 K$)

Instrument: Atmospheric Imaging Assembly (AIA)

Item	FY08	FY09	FY10	FY11	FY12	FY13	Total FY08-FY13
NASA Cost							
Phase A							
Phase B/C/D							
WBS 1.0 Instrument Development							
WBS 1.1 Program Management							
WBS 1.2 Systems Engineering							
WBS 1.3 Mission Assurance							
WBS 1.4 Instrument Subsystem							
WBS 1.4.1 Telescope subsystem (4) (SAO)							
WBS 1.4.2 Camera subsystem (4) (UK)							
WBS 1.4.3 Focal plane subsystem (4)							
WBS 1.4.4 Secondary spider subsystem (4)							
WBS 1.4.5 Electronics box							
WBS 1.4.6 Intra-instrument harness							
WBS 1.5 Guide telescope							
WBS 1.6 Software (flight and GSE)							
WBS 1.7 Ground support equipment							
WBS 1.8 Instrument and calibration							
WBS 1.9 Spacecraft I&T support (LMSAL & SAO)							
WBS 1.10 Launch support (LMSAL & SAO)							
WBS 1.11 Pre-launch science ops/DA/algorithm dev.							
WBS 1.12 Special launch service costs (N/A)							
WBS 1.13 Special ground data systems costs (N/A)							
WBS 1.14 Reserves (LMSAL &SAO)							
Phase E:							
WBS 2.0 Science Ops & Data Analysis	3,389	2,569	1,501	1,543	1,572	1,368	11,942
WBS 2.1 Post launch science operations (all)	2,258	1,713	1,001	1,029	1,048	912	7,961
WBS 2.2 Post launch data analysis (all)	1,131	856	500	514	524	456	3,981
E/PO:							
WBS 3.0 Education and Public Outreach	146	127	74	9	0	0	356
WBS 3.1 Pre-launch E/PO (all)	0	0	0	0	0	0	0
WBS 3.2 Post launch E/PO (all)	146	127	74	9	0	0	356
Total NASA External Costs	**3,535**	**2,696**	**1,575**	**1,552**	**1,572**	**1,369**	**12,298**
GSFC Costs	10	10	10	10	10	10	60
Total NASA Cost	**3,545**	**2,706**	**1,585**	**1,562**	**1,582**	**1,378**	**12,358**
Contributions							
WBS 1.0 UK Contribution	840	840	840	840	840	800	5,000
WBS 1.1 Hardware, I&T and calibration							
WBS 1.2 Science operations & exploitation	840	840	840	840	840	800	5,000
WBS 2.0 LM Contribution							
WBS 2.1 Fixed Assets	TBD	TBD	TBD	TBD	TBD	TBD	TBD
WBS 2.2 Directed IR	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Total Contributions	**840**	**840**	**840**	**840**	**840**	**800**	**5,000**
Total Invested Cost							

Table B-3: Summary of Elements of Costs

Instrument: Atmospheric Imaging Assembly (AIA)

Check One: ___X___ PHASE A _________BRIDGE PHASE

TABLE REDACTED

Table B-3: Summary of Elements of Costs

Instrument: Atmospheric Imaging Assembly (AIA)

Check One: _________ PHASE A ___X___ BRIDGE PHASE

TABLE REDACTED

Atmospheric Imaging Assembly (AIA) Rates

RATES REDACTED

TRAVEL WORKSHEET REDACTED

Table B-4. *Estimated cost savings from combining the HMI and AIA programs at LMSAL.*

Item	AIA	HMI	Sum AIA + HMI	Combined AIA + HMI	Cost Savings
NASA COST (RY $K)					
Phase A	3,007	2,884	5,891	4,919	972
Phase B/C/D	45,842	35,017	80,859	67,251	13,608
Program Management	3,766	3,766	7,532	5,696	1,836
Systems Engineering	2,457	3,448	5,905	4,609	1,296
Mission Assurance	2,343	3,563	5,906	4,502	1,404
Instrumentation (SAO)	15,185	0	15,185	15,185	0
Instrumentation (LMSAL)	10,510	15,973	26,483	20,651	5,832
Integration and Test (& GSE)	3,155	3,338	6,493	4,549	1,994
Pre-launch Science Preps	2,839	582	3,421	2,449	972
Pre-launch E/PO	563	0	563	563	0
Reserves	5,587	4,347	9,934	9,610	324
Phase E:	12,343	3,107	15,450	13,614	1,836
Post-launch MO&DA	11,997	3,107	15,104	13,268	1,836
Post-launch E/PO	356	0	356	356	0
TOTAL	**61,765**	**41,008**	**102,773**	**86,357**	**16,416**

G1. RESUMES AND CURRENT & PENDING SUPPORT

Attached are the resumes or curriculum vitae for the PI and Co-Is identified in §C1 Science Investigation and named in §A Cover Page and Proposal Summary. We have also provided resumes for key personnel identified in §E Management and Schedule and for key E/PO lead personnel. Current and pending support information has been provided for the PI and relevant Co-Is. Missing resumes/curriculum vitae may be submitted under separate cover.

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Alan M. Title
Principal Investigator

Senior Fellow, Lockheed Martin Corporation Advance Technology Center
Consulting Professor, Co-Director Stanford-Lockheed Institute for Space Research, Stanford University, Stanford, CA

Education

Ph.D., Physics, l966, California Institute of Technology
B.S., Physics, l96l, Columbia University
B.A., Mathematics, l960, University of California, Los Angeles

Awards, Honors and Professional Activities

Robert E. Gross Award, 1983, Scientist of the Year, Lockheed Corporation
Space Science Metal, American Institute Aeronautics and Astronautics, 1990
James Arthur Lectureship, Harvard University, 1991
LMMS Dan Tellep Award for Career Excellence, 1999
Goddard National Resource Award, 1999
NASA Public Service Metal, 2000
Aviation Week Laurels, 2000
Hale Prize, 2001
Chairman, Users' Committee, National Solar Observatory, 1984-1988
Member, LEST Scientific and Technical Advisory Committee, 1988-1995
Member, National Academy of Sciences Committee on Small Explorers, 1996
Member, National Academy of Sciences Committee on Solar Physics, 1996-1998
Member, Sun-Earth Connection Advisory Committee to NASA Administrator, 1998-1999
Member, Space Studies Board National Research Council, 1999-2001
Member, Executive Committee Space Studies Board National Research Council, 2000-2001
Member, Astronomy and Astrophysics Survey Committee Executive Panel, 1999-2000
Member, Executive Committee Advanced Solar Telescope, 2000-present
Member, Solar and Heliospheric Decadal Survey Committee Executive Panel, 1999-present
Principal Investigator, SOUP on Spacelab 2, 1974-1987
Principal Investigator, CIP on OSL, 1980-1994
Principal Investigator, TRACE Small Explorer Mission, 1993-present
Principal Investigator, Focal Plane Package for Solar B, 1998-present
Co-Investigator responsible for H Alpha Telescope of Skylab 2, 1968-1971
Co-Investigator responsible of Science Instrument, MDI for SOHO, 1988-present .

Technical Monographs

Selected Spectroheliograms, California Institute of Technology, 1967.

Fabry Perot Interferometers as Narrow Band Optical Filters, Harvard College Observatory, 1970.

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Title, A. M. and Berger, T. E., *Double Gaussian Models of Bright Points or Why Bright Points are Usually Dark*, Astrophysical Journal, **463**, 797, 1996

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C. J. Schrijver, A. M. Title, A. A. Ballegoojien, H. J. Hagenaar, R. A. Shine, *Sustaining the quiet photospheric network. A dynamic balance of flux emergence, fragmentation, merging, and cancellation*, Astrophysical Journal, **487**, 424, 1997

Berger, Thomas E., Löfdahl, Mats G., Shine, Richard A, Title, Alan M., *Measurements of Solar Magnetic Element Dispersal*, Astrophysical Journal, **506**, 439, 1998

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Berger, T. E.; Title, A. M., *On the Relation of G-Band Bright Points to the Photospheric Magnetic Field,* Astrophysical Journal, **553**, 449, 2001.

Role on AIA

Dr. Title maintains the ultimate responsibility for the management of the AIA investigation and is the formal liaison to NASA and to Lockheed Martin management.

Current and Pending Support

REDACTED

Jay Bookbinder
Co-Investigator

Education:

Ph.D. Astrophysics, Harvard University, 1985
B.S (with High Honors) Physics, Princeton University, 1979

Background

Performs research in solar physics with emphasis on space flight instrumentation. Conducts research in stellar astrophysics with an emphasis on observational constraints in coronal heating using HST, GRO, ASCA, ROSAT, IUE and EUVE, as well as ground-based observations using NASA's IRTF. PI or Lead Co-I on over 20 successful proposals. Co-Investigator on the following NASA satellite programs: TRACE and Solar-B's XRT. Program Manager on TRACE and XRT. Mission Scientist for the Constellation-X mission.

Role on AIA

Develop top-level science requirement and the flow-down of science requirements to all of the instrument subsystems, with an emphasis on the optomechanical aspects. Act as SAO Program Manager for SAO's development, fabrication and testing efforts, and oversee the systems engineering. Act as coordinator for interaction between AIA and SAO's XRT instrument.

Current and Pending Support

REDACTED

J. W. Brosius
Co-Investigator

Education

B.A., Physics, Franklin and Marshall College, Lancaster, PA, 1980

Ph.D., Physics University of Delaware through the Bartol Research Institute, Newark, DE, 1985.

Background

He has been working in the Laboratory for Astronomy and Solar Physics at NASA's Goddard Space Flight Center since September 1985, employed by Raytheon ITSS from September 1985 to February 2002, and by Catholic University since February 2002. Research interests include coronal magnetography, analysis of EUV, X-ray, and radio observations of the Sun, the interaction of nonthermal particle beams with stellar chromospheres, radiative transfer in magnetoactive plasma, theoretical models of the microwave emission from sunspots and loops, and magnetic field extrapolations. He has also published research on cometary plasma tail phenomena and stellar chromospheric emission variability and transition region modeling. He is active in educational outreach, and has chaired the SPD Popular Writing Awards Committee since 1999. Dr. Brosius is a member of the IAU, the AAS (and its SPD), and the AGU.

Bibliography of Selected Relevant Publications

"Measurements of Three-Dimensional Coronal Magnetic Fields from Coordinated EUV and Radio Observations of a Solar Active Region Sunspot," J. W. Brosius, E. Landi, J. W. Cook, J. S. Newmark, N. Gopalswamy, A. Lara, ApJ, **574**, in press (2002 July 20)

"Search for Evidence of Alpha Particle Beams During a Solar Flare Observed by the Coronal Diagnostic Spectrometer Aboard SOHO," J. W. Brosius}, ApJ, **435** (2001)

"Analysis of a Solar Active Region Extreme-Ultraviolet Spectrum From SERTS-97," J. W. Brosius, R. J. Thomas, J. M. Davila, E. Landi, ApJ, **543**, 1016 (2000)

Role on AIA:

Coordinate radio observations.

Current and Pending Support

REDACTED

Rock Bush
Co-Investigator

Education

Ph.D. in Physics	1983	University of California at Berkeley
M.A. in Physics	1976	University of California at Berkeley
B.S. in Physics	1974	University of Wyoming

Professional Employment

1991 - present	Senior Research Scientist, SOI Program Manager Hansen Experimental Physics Laboratory Stanford University, Stanford, CA
1984 - 1991	Research Associate, STAR Lab and Center for Space Science and Astrophysics Stanford University, Stanford, CA

Background

Performs research in magnetospheric and solar physics, with a current emphasis on solar cycle variation in solar radius and shape. As the Stanford University Program manager for the MDI instrument on SOHO, was responsible for coordinating the MDI development and is in charge of the MDI mission science planning and operations. Science collaborator on the following NASA satellite programs: TRACE, the FPP instrument on Solar-B, and the SECCHI instrument on STEREO.

Role on AIA

As the Stanford University Program Manger for the HMI instrument, is responsible for coordinating HMI and AIA development. Assist in instrument testing and calibration. Participate in planning and conducting mission operations. Play an active role in coordinating HMI with AIA and with other SDO investigations.

Current and Pending Support

REDACTED

Professor J. Leonard Culhane
Co-Investigator

Education

Ph.D., Physics, University College London, University College Dublin,1966
MSc, Physics, University College Dublin, 1960
BSc (1st Hons.), Physics, University, 1959

Background

1993-, Head, Department of Space and Climate Physics of UCL
1983-, Director, Mullard Space Science Laboratory of UCL
1981-, Professor of Physics, UCL
1976-81, Reader in Physics, UCL
1970-76, Lecturer in Physics, UCL
1969-70, Research Scientist/Member of the Research Laboratory, Lockheed Palo Alto Laboratory, USA
1967-69, Lecturer in Physics, UCL
1963-67, Research Assistant, Department of Physics, UC London (UCL)

Appointments

Member: Council, Particle Physics and Astronomy Research Council (1996-2000)
European Space Science Committee of the European Science Foundation (1998-)
COSPAR Commission E (1994-)
Chairman: Advisory Panel ESA Space Science Department (1994-00)
Visiting Professor, Institute of Space and Astronautical Science, Japan (1997).
Member: Evaluation Committee for Space Science in Norway (1994)
UK Delegate and Vice-President, ESA Science Programme Committee (1989-94)
UK BNSC Space Science Advisory Panel (1992-94)
UK SERC/BNSC Space Science Programme Board (1989-92)
Chairman: Royal Society British National Committee for Space Research (1989-92)
Member: ESA Space Science Advisory Committee (1985-88)
Chairman: ESA Astrophysics Working Group (1985-88)

Role on AIA

Oversee procurement and testing of AIA CCDs; Plan and implement UK science strategy for exploitation of solar atmosphere data from SDO; Co-ordinate UK involvement in AIA and H(V)MI if both selected.

Current and Pending Support

REDACTED

Bart De Pontieu
Co-Investigator

Physicist, Sr.
Lockheed Martin Advanced Technology Center

Education:

Physics/Astrophysics Ph.D. at the Max Planck Institute for extraterrestrial physics (MPE), Garching and University of Ghent, 1996

Thesis: Numerical Simulations of Chromospheric Spicules driven by Alfven Waves

Work Experience

Physicist, Sr. at Lockheed Martin Advanced Technology since 1998
Post-doc position at MPE, Garching, Germany from 1996 to 1998
Ph.D. at MPE, Garching, Germany from 1992 to 1996

Background

Dr. De Pontieu performs research in solar physics with emphasis on connections and interactions between photosphere, chromosphere, transition region and corona, as well as coronal seismology. He has extensive experience with ground-based observing, and is part of the TRACE Team, and E/PO lead at LMATC for Solar-B FPP.

Role in AIA

Co-lead of planning of coronal seismology studies
Co-lead of E/PO, participate in data analysis software development, and in coordinating with ground-based telescopes.

Current and Pending Support

REDACTED

Edward E. DeLuca
Co-Investigator

Education:
Ph.D. Astrophysics, 1986 University of Colorado
M.A. Astronomy, 1980, Wesleyan University
B.A. Astronomy, 1979, Wesleyan University

Background:
Solar physicist with research experience in numerical modeling, data analysis and space instrumentation. Fields of interest include, the solar dynamo, flux emergence, coronal loop models and coronal oscillations. Project Scientist and Co-I on the following satellite programs: SWATH, TRACE and Solar-B's XRT.

Role on AIA
Act as SAO Project Scientist for SAO's contributions to the instrument development, instrument testing, analysis software development and database development. SAO's lead scientist for the EPO program. Assist the SAO PI in developing top-level science requirement and the flow-down of science requirements to all of the instrument subsystems. Assist with the coordination of the AIA and Solar-B XRT.

Current and Pending Support

REDACTED

Bernhard Fleck
Co-Investigator

SOHO Project Scientist
ESA Research and Scientific Support Department, NASA/GSFC

Education

Ph.D., Physics, 1991, University of Würzburg, Germany. Thesis: Untersuchungen zur Dynamik oszillatorischer Vorgänge in der Sonnenatmosphäre

Diploma, Physics, 1987, University of Würzburg, Germany

Background

SOHO Project Scientist, ESA Research and Scientific Support Department, 1998 -
SOHO Deputy Project Scientist, ESA Space Science Department, 1993-1998
Research Scientist, University of Würzburg, 1991-1993

Other Relevant Experience

Study Scientist, Solar Orbiter
Co-I SOVIM (Solar Variability and Irradiance Monitor, to be flown on the ISS)

Memberships

IAU, SPD, Astronomische Gesellschaft, Board Solar Physics Section of the European Astronomical Society and European Physical Society, Board Joint Astrophysics Division of EAS and EPS

Role on AIA

Coordination with other ILWS missions and the European community.

Selected Recent Publications

Fleck, B.: 2001, Highlights from SOHO and Future Space Missions, in "The Dynamic Sun," Proc. 1999 Kanzelhoehe Summerschool, eds. A. Hanslmeier, M. Messerotti & A. Veronig, Kluwer, p. 1-41

Fleck, B., Brekke, P., Haugan, S., Sanchez Duarte, L., Domingo, V., Gurman, J.B., Poland, A.I.: 2000, Four Years of SOHO Discoveries - Some Highlights, ESA Bull. 102, 68-86

Fleck, B., Keller, C.U.: 2002, Solar Observing Facilities, in "The Dynamic Sun," ed. B.N. Dwivedi, Cambridge University Press, in press

Fleck, B., and the Solar Orbiter Study Team: 2001, Solar Orbiter - A High Resolution Mission to the Sun and Inner Heliosphere, SPIE Proc. Series, Vol. 4498, p. 1-16

O'Shea, E., Banerjee, D., Doyle, J.G., Fleck, B., Murtagh, F.: 2001, Active Region Oscillations, A&A 368, 1095-1107

Straus, Th., Severino, G., Deubner, F.-L., Fleck, B., Jefferies, S.M., Tarbell, T.: 1999, Observational constraints on models of the solar background spectrum, ApJ 516, 939-945

Current and Pending Support

REDACTED

Andrzej Fludra
Co-Investigator

Solar Physicist, Rutherford Appleton Laboratory, United Kingdom

Education

Ph.D., Physics, University of Wroclaw, Poland, 1988.
M.Sc., Wroclaw University of Technology, 1982

Experience

1994 to present: Research Scientist, Space Science & Technology Dept., RAL;
1988 - 1994: Post-Doctoral Research Associate, MSSL, University College, London
1982 - 1988: Research Assistant, Astronomical Institute, University of Wroclaw.

Background

Dr. Fludra is the Deputy Principal Investigator and Project Scientist for the Coronal Diagnostic Spectrometer (CDS) on SOHO, and has been managing CDS science operations at NASA GSFC since 1996. His current research concentrates on the study of the transition region and corona from extreme ultraviolet spectra, diagnostics of temperature and density structure of coronal holes, streamers and active regions, sunspot oscillations, coronal heating and elemental abundances. His interests include also X-ray spectroscopy and solar flares. He participated in the development and operations of the Bragg Crystal Spectrometer (BCS) on Yohkoh, was the leader of the BCS analysis software group, has studied coronal abundances and flare plasma dynamics from Yohkoh and Solar Maximum Mission data. He has developed numerical methods of the differential emission measure analysis.

Dr. Fludra is a Fellow of the Royal Astronomical Society, Member of the Institute of Physics, AGU and IAU. He is the author or co-author of over 80 publications in refereed journals and conference proceedings.

Role on AIA

Dr. Fludra is RAL's lead scientist for SDO, responsible for scientific and managerial issues at RAL.

Selected Publications

Fludra, A., Transition Region Oscillations above Sunspots, A&A, 368, 639 (2001)

Fludra, A., Intensity Oscillations in a Sunspot Plume, A&A, 344, L75 (1999)

Fludra, A., and Schmelz, J. T., The Absolute Coronal Abundances of Sulfur, Calcium, and Iron from Yohkoh-BCS Flare Spectra, A&A, 348, 286 (1999)

Fludra, A., Saba, J. L. R., Henoux, J-C., Murphy, R., Reames, D., Lemen, J. L., Strong, K. T., Sylwester, J., and Widing, K., Coronal Abundances, in: “The Many Faces of the Sun,” Strong, K. T., Saba, J. L. R, Haisch, B. M., and Schmelz, J. T. (eds), Springer-Verlag, pp.89-141 (1999).

Fludra, A., Del Zanna, G., Alexander, D., and Bromage, B., Electron Density and Temperature of the Lower Solar Corona, JGR, 104, No. A5, 9709 (1999)

Fludra, A., Brekke, P., Harrison, R. A., *et al*., Active Regions Observed in the EUV Light by the Coronal Diagnostic Spectrometer on SOHO, Sol. Phys., 175, 487 (1997)

Current and Pending Support

REDACTED

Stephen A. Fuselier
Co-Investigator

Physicist, Manager
Lockheed Martin Advanced Technology Center

Education

Ph.D., Physics, 1984, University of Iowa. Thesis: The Downshift of Electron Plasma Oscillations in the Electron Foreshock Region

MS., Physics, 1983, University of Iowa. Thesis: Doppler Shifted Ion Waves Upstream of the Earth's Bow Shock

B.S., Physics, 1981, University of Southern California

Background

Performs research in space plasma physics with emphasis on analysis of spacecraft data. Co-Investigator on the IMAGE, medium Explorer, Rosetta Lander Composition Experiment, Lead US Co-Investigator on the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA), Project Manager on the IMAGE/Far Ultraviolet Imager CCD electronics, IMAGE/Low Energy Neutral Atom Imager ion optics, ROSINA double focusing mass spectrometer electronics.

Role on AIA

Provide advice on program management and systems engineering. Participate in program reviews as a science advisor and experienced project manager. Participate in planning for, and conducting, mission operations, playing an active role in determining the geospace applicability of the observations.

Current and Pending Support

REDACTED

G. Allen Gary
Co-Investigator

Astrophysicist
Marshall Space Flight Center/ NASA

Education

Ph.D. Dissertation: "Construction of a Set of Self-Consistent Equations for Calculating the Strongly Interacting Particles"

Ph.D., Physics, University of Georgia, 1969

M. S., Physics, Georgia Institute of Technology, 1964

B. S., Physics, Georgia Institute of Technology, 1963

Background

For the last 20 years, he has been a member of the Solar Physics Team at the Marshall Space Flight Center/NASA, investigating the nature of coronal structures and solar magnetic fields. His research also includes the general study of the magnetic field's configuration, evolution, and morphology together with estimation of the energy content of active regions. His theoretical work involves developing models of linear and nonlinear force-free magnetic fields and electric currents in the solar chromosphere-corona. The theories extrapolate upward the photospheric vector magnetic field as measured by the MSFC Vector Magnetograph. General data reduction and analysis of the unique MSFC magnetograms are being carried out using various mathematical models, computer and image analysis codes. He is also participating in developing a space-based vector magnetograph which will be one of the core instruments for studying the processes that give rise to solar activity in the solar atmosphere.

Role on AIA

Participate in data analysis to provide expertise on coronal measurements and magnetic field extrapolations. Participate in planning for, and conducting, mission operations. Play an active role in coordinating AIA with the other SDO investigations, especially, as applied to coronal magnetic field configurations and morphology using parametric transformation analysis.

Current and Pending Support

REDACTED

Leon Golub
Co-Investigator

Education

Ph.D. Physics, M.I.T., 1972
B.S. (with honors) Physics, C.C.N.Y., 1967

Background:

Performs research in solar physics with emphasis on space flight instrumentation and on understanding magnetic field-related dynamics of coronal plasmas. Conducts research in stellar astrophysics with an emphasis on observational constraints in coronal heating. Has been PI or lead Co-I on over 40 successful proposals. Principal Investigator or Co-I on the following rocket and satellite programs: NIXT, HRSO, SWATH, TRACE and Solar-B's XRT.

Role on AIA:

Develop top-level science requirement and the flow-down of science requirements to all of the instrument subsystems, with an emphasis on the optomechanical aspects. Act as SAO PI for the overall SAO development, fabrication and testing efforts, and oversee the systems engineering. Act as coordinator for interaction between AIA and SAO's XRT instrument.

Current and Pending Support

REDACTED

Joseph B. Gurman
Co-Investigator

Astrophysicist, Solar Physics Branch, Laboratory for Astronomy and Solar Physics, NASA Goddard Space Flight Center

Education

Ph. D., Astrophysics, University of Colorado, 1979; thesis: *Vector Magnetic Fields and Sunspot Umbral Models*

M.S., Physics, University of Colorado, 1974

A.B. (*mcl*), Astronomy, Harvard College, 1972

Background

U.S. Project Scientist for the *Solar and Heliospheric Observatory* (1998-); U.S. Deputy Project Scientist for the *Solar and Heliospheric Observatory* (1996-1998

Co-Investigator, Extreme ultraviolet Imaging Telescope (EIT) on *SOHO* (1989-), responsible for ground operations, analysis software, data archiving and dissemination

TRACE Mission Scientist (2002 -)

Project Scientist, *Solar Maximum Mission (SMM)* (1986-1989)

Experiment Manager, *SMM* UVSP (1986-1989)

Science Team Member, Ultraviolet Spectrometer and Polarimeter (UVSP) on the *Solar Maximum Mission* (1979-1989)

Facility Scientist, Solar Data Analysis Center (SDAC)/*SMM* Data Analysis Center (1981-)

Role on AIA

Participate in defining instrument requirements; participate in planning for and conducting mission operations; interface with Goddard Project management; participate in design and operation of instrument data processing and archive to insure service of data to as wide a community as possible.

Current and Pending Support

REDACTED

Louise Kim Harra
Co-Investigator

Education
Queens University, Belfast, N. Ireland
Ph.D., Physics, *"Spectroscopic Diagnostics for Solar and Laboratory Plasmas,"* Oct 1990-Aug 1993
BSc (Hons), Applied Maths and Physics, Oct 1987-Jun 1990

Background
Mullard Space Science Laboratory (UCL)
Holmbury St Mary, Dorking, Surrey, RH5 6NT
PPARC Advanced Fellow (Oct 1999-Sep 2004)
Mullard Space Science Laboratory (UCL)
Holmbury St Mary, Dorking, Surrey, RH5 6NT, Research Fellow in solar physics (Sep 1995 - Sep 1999)
University of Birmingham Edgbaston, Birmingham *Research Fellow in Solar Physics* (Jan 1995 - Sep 1995)
Institute of Space and Astronautical Science Sagamihara-shi, Kanagawa-ken, 229 Japan *Resident scientist for the UK instrument on Yohkoh* (Oct 1993-Jan 1995)

Publications
47 refereed papers and 24 conference proceedings.

Awards
Co-applicant on the MSSL PPARC Rolling grant (2002-2004)
Co-applicant on the SOHO operations grant (2001-2003)
PIPSS award for space weather (2000-2003)
Co-applicant for Solar Physics Rolling Grant (2000-2002)
PPARC advanced fellowship (1999-2004)
Several Royal Society and British Council grants for collaborative work in Europe and Japan.

Positions of Responsibility
Leader of the solar physics group at MSSL.
Project Scientist for the Solar-B EUV imaging spectrometer instrument.
Pastoral Tutor for MSSL's Ph.D. students from all research groups.
Scientific organizer of workshop on quiet Sun heating at MEDOC (June 2001).
Organizer of International Workshop on Active Region Dynamics at MEDOC (March 1999)
Course director of PPARC advanced summer school in solar physics (Sep 3-8, 2000).
Co-organizer of RAS Discussion Meeting on 'Coronal Heating in the Sun and Late Type Stars' - Jan 12, 2001.

Role on AIA
Participate in pre-launch science planning.

Current and Pending Support

REDACTED

Richard A. Harrison
Co-Investigator

Space Science & Technology Department, Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire, OX11 0QX

Education

Ph.D FRAS
B.Sc.(Hons)

Experience

Head of Solar Physics Group & Band 2 (Individual Merit) Scientist
PI on ESA/NASA Solar & Heliospheric Observatory (Coronal Diagnostic Spectrometer)
PI on NASA STEREO Mission (Heliospheric Imager)
Honorary Professor School of Maths and Statistics, University of St Andrews

Academic Career

1986 - to date – Solar Physicist - Space Science & Technology Dept., RAL.
1985-86 - Long Term Visiting Scientist, High Altitude Observatory, Boulder, Colorado.
1983-84 - SERC Research Fellow, Space Research Dept., University of Birmingham, UK.
1983 – PhD in solar physics – Space Research Department, University of Birmingham, UK.
Solar physicist, with research interests in mass ejection processes, coronal structure and quiet

Background

Sun processes, in particular through the detection, analysis and interpretation of extreme UV spectra from solar plasmas. Author of over 130 full research papers in the refereed literature and published conference proceedings, including a number of invited reviews and book chapters. Expertise in instrument development, management and operation has led to hardware roles in several missions: Co-investigator on the NASA Solar Maximum Mission (1980-1989) and the Transition Region and Coronal Explorer (TRACE; launched 1998). Principal Investigator for the Coronal Diagnostic Spectrometer instrument on the ESA/NASA Solar and Heliospheric Observatory (SOHO; launched 1995). Principal Investigator for the Heliospheric Imager instrument on the NASA STEREO mission (launch 2005). Member of Solar-B EIS hardware/science team, and member of successful proposing/study team for the ESA Solar Orbiter mission. Served on ESA Solar System Working Group, ESA Solar Physics Planning Group, NASA SDO Payload Definition Team and other committees.

Role on AIA

Dr. Harrison will have overall scientific direction for the activities at RAL with special emphasis on CMEs and coordination with spectral observations.

Current and Pending Support

REDACTED

Donald M. Hassler
Co-Investigator

Education
Ph.D. Physics, University of Colorado, Boulder, 1990.
M.S. Physics, University of Colorado, Boulder, 1988.
B.A. Physics, Kenyon College, Gambier, Ohio, 1984.

Employment
Senior Research Scientist (3/97 - present)
Head, Solar & Stellar Physics Group (9/99 - present), Instrumentation and Space Research Division, Southwest Research Institute, Boulder, CO
Scientist, High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO (12/93 - 3/97)
Physicist, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA (1/92 - 12/93)
NSF-NATO Postdoctoral Fellow, Institut d'Astrophysique Spatiale Verrieres-le-Buisson and Orsay, France (6/91-12/91, 1/94-7/94)
Research Associate, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO (1/91 - 6/91)

Background
Dr. Hassler the PI of the Atmospheric Imaging Spectrograph (AIS) proposal for SDO. He is also head of the Solar and Stellar Physics Group in the Department of Space Studies at SwRI. His scientific interests include understanding the physics of the outer solar atmosphere, from the chromosphere-corona interface to large-scale coronal structures. His research emphasis is focused on the observational aspects of Solar Physics and the development of new instrumentation. He has an experimental background in ultraviolet spectroscopy of the solar atmosphere and the calibration and characterization of UV and EUV space instruments. Dr. Hassler has been either Principal Investigator or Co-Investigator on seven sounding rocket flights and participated in the first successful flight of Ultraviolet Coronagraph Spectrometer (UVCS) on the Spartan 201 Space Shuttle Experiment (STS-56). He is a funded Co-Investigator with the SUMER instrument and an Associate Scientist with the CDS instrument on SOHO, and is a funded Co-I with the STEREO/SECCHI Team.

Role on AIA
If AIS and AIA are both selected, will coordinate science planning and explore joint hardware and analysis efforts to reduce overall costs to the SDO program.

Current and Pending Support

REDACTED

Neal Hurlburt
Co-Investigator

Education
B.Sc., Physics, The Evergreen State College, 1977
Ph.D., Astrogeophysics, University of Colorado, Boulder, 1983

Background
He spent the next several years developing his interests in astrophysical fluid dynamics, supercomputing and visualization at various institutions, including the Department of Applied Mathematics and Theoretical Physics, University of Cambridge, England and The John von Neumann National Supercomputer Center. Since 1990, has been a staff physicist at the Lockheed Martin Solar and Astrophysics Laboratory in Palo Alto, California, where he oversees the TRACE Data Center, the development of the Solar-B/FPP Data Center, and department Theory Group.

Areas of Technical Specialization
Dr. Hurlburt's research revolves around solar and stellar MHD theory with an emphasis towards the application of modern computational and visualization technologies. He is currently active in numerical simulation of and nonlinear compressible magnetoconvection, in the comparison of these simulations to high-resolution solar observations, and in the visualization and management of the large datasets resulting from both simulation and observation. Dr. Hurlburt has developed and run his large-scale numerical simulations on many varieties of vector and parallel supercomputers. He has devised, developed and managed several substantial data and visualization systems which exploit the latest in high-performance computing.

Roles in AIA
Design and manage AIA data capture, processing and archiving system and it's integration into wider, LWS data system; MHD modeling of active regions

Current and Pending Support

REDACTED

Christoph U. Keller
Co-Investigator

Associate Astronomer/Tenure
National Solar Observatory

Education

Ph.D., Natural Sciences, 1992, Swiss Federal Institute of Technology, Zurich, Switzerland. Thesis: *High Resolution Observations of Solar Magnetic Fields*

M.S., Physics, 1988, Swiss Federal Institute of Technology, Zurich, Switzerland

Background

Performs research in solar physics with emphasis on ground-based instrumentation

Co-Investigator on the following programs: Advanced Technology Solar Telescope (ATST), Frequency-Agile Solar Radio Telescope (FASR), SOLIS Vector-Spectromagnetograph, Solar-B/FPI. Telescope Scientist for McMath-Pierce facility

Role on AIA

Coordinate observations with AIA and the ground-based SOLIS facility.

Current and Pending Support

REDACTED

Alexander G. Kosovichev
Co-Investigator

09/94 -- present: Senior Research Scientist, W.W. Hansen Experimental Physics Laboratory, Stanford University
10/90 -- 09/94: Senior Research Associate, Institute of Astronomy, University of Cambridge
11/79 -- 10/90: member of the scientific staff of the Crimean Astrophysical Observatory

Education
D.Sc., Astrophysics, 1990, Leningrad State University;
Ph.D., Computational and Applied Mathematics, 1980, Moscow State University;
M.S., Plasma Physics, 1975, Novosibirsk State University.

Recent Selected Publications
Kosovichev, A.G., Duvall, T.L., Jr and Scherrer, P.H., 2000, Time-Distance Inversion Methods and Results, *Solar Physics*, 192, 159-176.
Birch, A.C. and Kosovichev, A.G., 2000, Travel Time Sensitivity Kernels, *Solar Physics*, 192, 193-201.
Kosovichev, A. G., 1999, Inversion Methods in Helioseismology and Solar Tomography, *J. Comp. Appl. Math.*, 109, 1-39.
Kosovichev, A. G., 1996, Tomographic imaging of the Sun's interior, *Astrophysical Journal,* 461, L55-L57.
Kosovichev, A.G., 1999, Flows in the Solar Convection Zone, in: Magnetic Helicity in Space and Laboratory Plasmas, *Geophysical Monograph 111*, American Geophysical Union, Washington, D.C., p. 83-91.
Nigam, R. and Kosovichev, A.G. 1999, Source of solar acoustic modes, *Astrophysical Journal*, 514, L53-L56.
Benevolenskaya, E. E., Hoeksema, J. T., Kosovichev, A. G., Scherrer, P. H. 1999, The Interaction of New and Old Magnetic Fluxes at the Beginning of Solar Cycle 23, *Astrophysical Journal,* 517, L163-L166.
Kosovichev, A.G. and Zharkova, V.V., 1998, Solar Flares Spark Quakes in the Sun's Interior, *Nature*, 393, 317-318.
Kosovichev, A. G. and Schou, J., 1997, Detection of Zonal Shear Flows beneath the Sun's Surface from f-Mode Frequency Splitting, *Astrophysical Journal*, 482, L207-L210.
Kosovichev A.G., 1996, Helioseismic constraints on the gradient of angular velocity at the base of the solar convection zone, *Astrophysical Journal*, 469, L61-L64.

Role on AIA
Science coordination planning in conjunction with the HMI investigation.

Current and Pending Support

REDACTED

James R. Lemen
Co-Investigator

Physicist, Consultant
Lockheed Martin Advanced Technology Center

Education

Ph.D., Physics, Columbia University, 1981
B.A. (with distinction), Physics, University of Iowa, 1976

Background

Performs research in solar physics with emphasis on coronal studies of flares, CMEs and the active Sun. Co-investigation on the following NASA satellite programs: SXT on Yohkoh; EIT on SOHO; SECCHI on STEREO. Deputy PI for operations on the SXT program. PI of the Yohkoh Public Outreach Project. Project leader and principal scientist of the GOES SXI program.

Role on AIA

Participate in the definition instrumental requirements and the hardware development program. This will include the development of the test and calibration programs and the preparation for missions operations. Participate in the science planning and the analysis of AIA data. Act as a liaison to the GOES SXI datasets.

Current and Pending Support

REDACTED

Petrus C. Martens
Co-Investigator

Associate Research Professor
Department of Physics, Montana State University

Education

Cum Laude Ph.D., Theoretical Astrophysics, Utrecht University in The Netherlands, 1983

Experience

Petrus C. Martens has been an Associate Research Professor with Montana State University in Bozeman since January, 1999

European Space Agency as Science Operations Coordinator for the ESA/NASA SOHO mission (1993-1998)

Research scientist at Lockheed Solar & Astrophysics lab, making regular tours to Japan for operations (1990-1993)

Background

Prof. Marten’s research focuses on issues related to data from current space missions: formation and eruption of prominences, flare topology and particle acceleration, coronal heating and the thermal structure of loops, and the solar wind. He is supervising two graduate students, co-advises five more, and regularly teaches graduate courses, such as “MHD and Plasma Physics of the Sun” and “Electro- and Magnetostatics” (Jackson).

Role on AIA

- Direct and administrate the MSU part of the AIA investigation
- Coordinate the Coronal Heating and Irradiance: Thermal Structure and Emission Research Theme through the organization of meetings, workshops and proposals, to include investigators worldwide
- Contribute to instrument definition and calibration, in particular through characterization of the AIA point spread functions and thermal coverage
- Supervise two MSU graduate students who for their practical training will take part in the integration and calibration of AIA, and whose thesis research is AIA related
- Direct MSU contributions to data analysis software for AIA DEM analysis

Current and Pending Support

REDACTED

David E. McKenzie
Co-Investigator

Research Scientist
Department of Physics, Montana State University

Education

Ph.D., University of Delaware, 1997

Background

David McKenzie joined the Solar Physics Group at Montana State University in January 1997. He was a member of the Creative Design and Definition Team for the very successful Yohkoh Public Outreach Project, and participates in numerous other Education/Public Outreach efforts. As a member of the Yohkoh operations team, Dr. McKenzie visited Japan frequently for operations duties, and continues to collaborate with colleagues from Japanese, American, and European institutions in the analysis of solar X-ray data. He received his.

Dr. McKenzie's primary research interests include plasma flow fields near flare sites, topology of flare structures, magnetic reconnection, and education and public outreach. A complete vita and list of publications are available at his home page. Some papers relevant to the AIA investigation are listed below.

Role on AIA

Direct the MSU portion of AIA Education/Public Outreach

Contribute to development, implementation, and assessment of AIA E/PO curricular materials

Contribute to instrument definition and calibration, including characterization of instrument response (sensitivity, thermal coverage, point spread functions)

Contribute to data analysis software

Selected Publications

"Downflows and Structure above LDE Arcades: Possible Signatures of Reconnection?," by McKenzie, D. E., H.S. Hudson, in *Proceedings of The University of Tokyo Symposium in 2000 on Magnetic Reconnection in Space and Laboratory Plasmas*, eds. M. Hoshino, R. L. Stenzel, and K. Shibata, Earth Planets Space (2001), 53, 577

"Supra-arcade Downflows in Long-Duration Solar Flare Events," by McKenzie, D. E., Sol. Phys., **381** (2000)

"Large Doppler shifts in X-ray plasma: an explosive start to coronal mass ejection," by Innes, D. W. Curdt, R. Schwenn, S. Solanki, G. Stenborg, D. E. McKenzie, ApJ, **L249** (2001)

"X-Ray Observations of Motions and Structure Above a Solar Flare Arcade," by McKenzie, D. E., H. S. Hudson, ApJ, **L93** (1999)

"A Space-Age Portrait of the Active Sun," by McKenzie, D. E., T. Slater in *The Physics Teacher*, (October 1998)

Current and Pending Support

REDACTED

Thomas R. Metcalf
Co-Investigator

Physicist, Staff
Lockheed Martin Advanced Technology Center

Education

Ph.D., Physics, 1990, University of California, San Diego. Thesis: *Flare Heating and Ionization of the Low Solar Chromosphere*

M.S., Physics, 1985, University of California, San Diego

B.A., Physics, 1983, University of California, San Diego

Background

Dr. Metcalf performs research in solar physics with emphasis on the energetics of solar magnetic fields, solar flares, coronal heating, and image reconstruction. Dr. Metcalf has considerable experience in solar research and the analysis of data from vector magnetographs. He has been involved in a number of Yohkoh related research projects, including analyses of active region and flare loop heating and the relationship between flares and electric currents derived from vector magnetic field data. He was responsible for the development of a new image reconstruction algorithm for the Yohkoh Hard X-ray Telescope and algorithms for the reduction of vector magnetic field data and the resolution of the 180-degree ambiguity in the vector field. Recently, Dr. Metcalf initiated a new project to quantify the magnetic free energy in active regions and to study the relationship between magnetic free energy and coronal activity.

Role on AIA

Dr. Metcalf is responsible for the study of the energetics of active regions and coronal heating through vector magnetic field observations.

Current and Pending Support

REDACTED

Zoran Mikic
Co-Investigator

Education

Ph.D., University of California, Berkeley, 1985.
M.S., University of California, Berkeley, 1980.
B.Sc., University of London, Queen Mary College, 1979.

Background

Dr. Mikic is a computational plasma physicist with experience in particle and magnetohydrodynamic (MHD) simulation of solar and fusion plasmas. His interests in solar physics include large-scale MHD modeling of the solar corona, the eruption of coronal magnetic field arcades, coronal mass ejections, the three-dimensional structure of the solar corona, modeling of active-region coronal magnetic fields, coronal heating, and solar flares.

Role on AIA

Dr. Mikic will participate in modeling activities, including the MHD modeling of the magnetic and thermal structure of active regions, global modeling of the corona and solar wind, and in studying the relationship between EUV emission and coronal heating.

Representative Publications

Z. Mikic and J. A. Linker, "Disruption of Coronal Magnetic Field Arcades," *Astrophys. J.*, **430**, 898 (1994).

A. N. McClymont and Z. Mikic, "Thickness Variations along Coronal Loops Inferred from Vector Magnetograph Data," *Astrophys. J.*, **422**, 899 (1994).

J. A. Linker and Z. Mikic, "Disruption of a Helmet Streamer by Photospheric Shear," *Astrophys. J. Letters*, **438**, L45 (1995).

A. N. McClymont, L. Jiao, and Z. Mikic, "Problems and Progress in Computing Three-Dimensional Coronal Active Region Magnetic Fields from Boundary Data," *Solar Phys.*, **174**, 191 (1997).

J. Lee, S. M. White, M. R. Kundu, Z. Mikic, and A. N. McClymont, "A Test for Coronal Magnetic Field Extrapolations," *Astrophys. J.*, **510**, 413 (1999).

Z. Mikic, J. A. Linker, D. D. Schnack, R. Lionello, and A. Tarditi, "Magnetohydrodynamic Modeling of the Global Solar Corona," *Phys. Plasmas*, **6**, 2217 (1999).

Current and Pending Support

REDACTED

Nariaki V. Nitta
Co-Investigator

Education

Ph.D., Astronomy, University of Tokyo, 1984. Thesis: *The Continuum Spectrum of Solar Flares*

M.S., Astronomy, University of Tokyo, 1981

B.S., Astronomy, University of Tokyo, 1979

Employment

Lockheed Martin Solar and Astrophysics Laboratory (1996-present)

Applied Research Corporation (1990-1995)

National Astronomical Observatory of Japan (1989-1990)

University of Maryland (1987-1989)

Background

Performs research in solar physics with emphasis on systematic analysis of multi-wavelength data, including soft/hard X-ray, EUV, UV, optical and mm-hectometric radio. One of the key members of Yohkoh/SXT to provide software and scientific support and to conduct real-time planning. Recent research focuses on the relation between small-scale and large-scale magnetic field in the context of CME initiation.

Publications

More than 70 papers in refereed journals.

Role on AIA

Participate in developing analysis software. Participate in implementing optimum observing sequences for observing CMEs and decoupling them from flare effects. Play an active role in coordinating AIA with ground-based observatories, in-situ experiments and GOES/SXI to obtain datasets that are key to the understanding of eruptive events.

Current and Pending Support

REDACTED

Åke Nordlund
Co-Investigator

Physicist, Associate Professor,
Niels Bohr Institute for Astronomy, Physics, and Geophysics, Univ. of Copenhagen

Education

Ph.D., Physics, University of Stockholm, 1976. Thesis: *Theories of Stellar Convection*

Employment

1979-present, Associate Professor, Astronomical Observatory/NBIfAFG, Univ. of Cph.

Background

Performs research on astrophysical magnetohydrodynamics and turbulence, with emphasis on solar physics, astrophysical dynamos, and magnetic dissipation.

Role on AIA

Participate in defining the scientific objectives of the mission. Participate in analyses of the results obtained, in particular by forward comparisons with results from realistic, supercomputer based models of the solar corona, transition zone, and chromosphere.

Current and Pending Support

REDACTED

Eric R Priest
Co-Investigator

Professor
St Andrews University, Scotland

Education

Ph.D., Applied Mathematics, University of Leeds, 1969. Thesis: *MHD Neutral Point Theory*
B.Sc. (with 1st class honours), Mathematics, Nottingham University, 1965

Background

Performs research on solar magnetohydrodynamics and is part of the Solar Theory Group at St Andrews, which consists currently of 5 permanent staff, 3 support staff, 10 postdocs and 14 Ph.D. students, all of whom are working on Solar MHD.

Has written 380 research papers and written or edited 17 books, including *Solar Magnetohydrodynamics (1982)* and with TG Forbes *Magnetic Reconnection (2000).*

Research topics include: magnetic reconnection, coronal heating, coronal loops, prominences, solar flares.

Role on AIA

Playing an active role in interpreting the observations of the solar surface and atmosphere and developing new theories to explain those observations. In particular, the aims will be to: understand the structure and heating of the solar transition region and corona; understand the ways in which magnetic reconnection operates in the solar atmosphere; develop models for the way magnetic flux emerges and interacts with the overlying environment and is reprocessed.

Current and Pending Support

REDACTED

Goran Scharmer
Co-Investigator

Director of the Institute for Solar Physics of the Royal Swedish Academy of Sciences
Professor at the Royal Swedish Academy of Sciences

Background

1990, Professor position, Royal Swedish Academy of Sciences
1986-90, Postdoctoral research associate position, Royal Swedish Academy of Sciences
1984, Appointed "docent" at Stockholm University
1983-86, Postdoctoral research position, Stockholm University
1982-83, Postdoctoral research position, High Altitude Observatory
1981-82, Postdoctoral research position, Stockholm University
1981, Ph.D. degree at Stockholm Observatory
1975-81, Ph.D. student in astronomy at Stockholm Observatory
1979-80, Military service
1971-74, Mathematics & Physics undergraduate program, Stockholm University
1967-70, Swedish high school, science program, Kyrkerrskolan, Falk ping
1951, Born on October 12th in Ulricehamn

Awards and Honors

Letterstedt award of the Royal Swedish Academy of Sciences, 1985
Member of the Royal Swedish Academy of Sciences, 1995
Foreign member of the Norwegian Academy of Science and Letters, 1998

Short description of Research

My thesis work started on observational work but switched to non-LTE radiative transfer in 1978. Radiative transfer became the topic of my thesis and I continued this research until approximately 1985. During 1983-85 I was responsible for the design of the Swedish Vacuum Solar Telescope (SVST) and later for all of its instrumentation. I have supervised three Ph.D. students: Mats Carlsson on non-LTE radiative transfer, Anders Johannesson on two-dimensional spectroscopy and Mats Lfdahl on phase diversity techniques for post-correction of images degraded by telescope and atmospheric aberrations. I also supervised the MSc thesis of Henrik Blomberg on adaptive optics. I am collaborating with a number of scientists in U.S.A and in Germany on interpreting data from SVST and on developing phase diversity methods and adaptive optics for the SVST and the new 1-meter solar telescope in La Palma. During the last three years, I have been responsible for the optical and mechanical design as well as the construction of the new solar telescope that recently and successfully had first light.

Role on AIA

Prof. Scharmer will coordinate observations analysis with the SVST and other ground-based observatories.

Current and Pending Support

REDACTED

P. Scherrer
Co-Investigator

Professor, Department of Physics and W.W. Hansen Experimental Physics Laboratory, Stanford University

Education
A.B. Physics, University of California at Berkeley, 1968.
Ph.D. Physics, University of California at Berkeley, 1973.

Background
Principal Investigator, Solar Oscillations Investigation/Michelson Doppler Imager (SOI/MDI) on SOHO, 1988-present
Member, SOHO Science Working Team, 1987-present.
Chair, SOHO Helioseismology Working Group.
Principal Investigator, "Structure of Solar Magnetic and Velocity Fields" (NASA), "Dynamic Observations of Solar Magnetic and Velocity Fields" (NSF), and "Geomagnetic Disturbances" (ONR).
Co-Investigator, "Transition Region and Coronal Explorer" (TRACE).
Stanford Chair, Stanford-Lockheed Institute for Astrophysical and Space Research, 1992-present.

Relevant References:

T.L. Duvall Jr., A.G. Kosovichev, P.H. Scherrer, R.S. Bogart, R.L. Bush, C. DeForest, J.T. Hoeksema, J. Schou, J.L.R. Saba, T.D. Tarbell, A.M. Title, C.J. Wolfson, and P.N. Milford, "Time-Distance Helioseismology with the MDI Instrument: Initial Results," *Solar Physics*, **170**, 63-73, 1997.

A.G. Kosovichev, T.L. Duvall, Jr., and P.H. Scherrer, "Time-Distance Inversion Methods and Results," *Solar Physics,* **192**, 159-176, 2000.

J. Schou , H.M. Antia, S. Basu, R.S. Bogart, R.I. Bush, S.M. Chitre, J. Christensen-Dalsgaard, M.P. DiMauro, W.A. Dziembowski, A. Eff-Darwich, D.O. Gough, D.A. Haber, J.T. Hoeksema, R. Howe, S.G. Korzennik, A.G. Kosovichev, R.M. Larsen, F.P. Pijpers, P.H. Scherrer, T. Sekii, T.D. Tarbell, A.M. Title, M.J. Thompson, J. Toomre, "Helioseismic Studies with SOI-MDI of Differential Rotation in the Solar Envelope," *Astrophysical Journal,* **505**, 390, 1998.

Scherrer, P.H; Bogart, R.S.; Bush, R.I.; Hoeksema, J.T.; Kosovichev, A.G.; Schou, J.; Rosenberg, W.; Springer, L.; Tarbell, T.D.; Title, A.; Wolfson, C.J.; Zayer, I.; and the MDI Engineering Team, "The Solar Oscillations Investigation - Michelson Doppler Imager," *Solar Physics,* **162**, 129-188, 1995.

Role on AIA
As the proposed PI of HMI, will coordinate HMI science planning with the AIA team.

Current and Pending Support
REDACTED

Carolus J. Schrijver
Co-Investigator

Physicist, Staff
Lockheed Martin Advanced Technology Center

Education

Doctorate (summa cum laude), Mathematics, Physics, and Astronomy, 1986
University of Utrecht, The Netherlands. Thesis: *Stellar magnetic activity*

Background

Performs research in solar physics with emphasis on magnetic field transport, coronal fields and plasma, and the solar-stellar connection. Co-Investigator on TRACE

Role on AIA

Science Lead for the AIA investigation, with particular interest in comparison of coronal and surface fields, and in the connections to geospace. Participate in planning for, and conducting, mission operations. Play an active role in coordinating with other SDO, ILWS, and solar-physics investigations.

Current and Pending Support

REDACTED

Richard A. Shine
Co-Investigator

Staff Physicist
Lockheed Martin Advanced Technology Center

Education

Ph.D., Astrophysics, University of Colorado, 1973
B.S., Physics and Mathematics, University of Wisconsin, 1968

Background

High resolution solar observations in the visible and EUV, data analysis techniques, solar activity and flares, line formation in stellar atmospheres

Role on AIA

Determine requirements for mission operations and science planning. Assist in data processing and analysis plans. Participate in software development and instrument testing. After launch, participate in science operations and coordination of AIA with other solar observatories, especially Solar-B and groundbased telescopes.

Current and Pending Support

REDACTED

Larry A. Springer
Program Manager

Education
MS, Computer Science, University of Santa Clara, 1976
BS, Electrical Engineering, University of California Davis, 1972

Professional Employment
Lockheed Martin Solar and Astrophysics Laboratory, 1976 – present
Lockheed Missiles & Space Company 1972 to 1976

Background
Background in instrument development: Program Manager of the LMSAL part of SECCHI for STEREO. Program Manager of SXI for GOES from start to CDR. Chief Engineer of SOI/MDI for SOHO. Electronics Lead Engineer of CLAES for UARS. Electronic Design Engineer on XRP for SMM

AIA Research Interests and Investigation Role
Program Manager for the AIA instrument

Current and Pending Support

REDACTED

Theodore D. Tarbell
Co-Investigator

Staff Physicist
Lockheed Martin Advanced Technology Center

Education

Ph.D., Physics, California Institute of Technology, 1976. Thesis: *Semiconvection in Halo Stars and the Primordial Helium Abundance*

A.B., Physics, Harvard University, 1971

Background

Performs research in solar physics and image processing, specializing in high resolution observations of magnetic and velocity fields in the solar atmosphere. Performs theoretical analysis, testing, and calibration of optical imaging and tracking systems, with emphasis on space flight instrumentation. Co-Investigator on the following NASA satellite programs: SOUP on Spacelab 2, CIP on OSL, SOI-MDI on SOHO, TRACE, Solar-B FPP, and SECCHI on STEREO.

Role on AIA

Establish requirements and conceptual design for Guide Telescope, ISS, UV channel, and other instrument characteristics. Assist in instrument testing and calibration. Participate in planning and conducting mission operations. Play an active role in coordinating AIA with the Solar-B mission and with other SDO investigations, especially HMI if the Stanford-led proposal is selected.

Current and Pending Support

REDACTED

Dr. Nicholas R Waltham
Co-Investigator

Head of CLRC/RAL/SSTD Imaging Systems Division

Education

Ph.D., Physics University of Durham, 1980-1983
B.Sc (IIi), Physics University of Durham, 1977-1980

Professional Memberships

M.I.E.E., Member of the Institute of Electrical Engineers
C. Eng, Chartered Engineer

Background

2001-date Head of Imaging Systems Division, Space Science Department, Rutherford Appleton Laboratory.

1. Lead Design Engineer for the NASA STEREO/SECCHI CCD camera electronics.
2. Project Director for the BNSC/MoD TOPSAT high resolution Earth Observation CCD camera system.
3. Project Director for the PPARC/ESO ground-based VISTA Telescope IR survey camera instrument.
4. Project Director for the PPARC ground-based SUBARU/FMOS multi-object IR spectrograph camera system.
5. Project Director for the BNSC-funded TOPSAT-2 high resolution Earth Observation CCD camera.

2001 Individual Merit Promotion to CLRC/RAL Band 2.

1996-2001 Head of CCD Technology Group, Space Science Department, Rutherford Appleton Laboratory.

1. Lead Design Engineer for the USAF CORIOLIS/SMEI (Solar Mass Ejection Imager) CCD cameras with Birmingham University and UCSD.
2. Systems Engineer for the ESA/ROSETTA/Ptolemy Evolved Gas Analyzer, and Work Package Manager for the instrument electronics and on-board software.
3. Lead Design Engineer for the NASA STEREO/SECCHI CCD camera electronics.
4. System Design of the BNSC/MoD TOPSAT high resolution Earth Observation CCD camera system. Work Package Manager for the CCD detectors and camera electronics.
5. Work Package Manager for the ESA/SMART-1/DCIXS X-ray fluorescent spectrometer CCD detectors.
6. Technical/Programme lead in the CLRC/RAL/SSTD development of science-grade CMOS Active Pixel Sensors.

Role on AIA

Responsible for the development of the CCD camera.

Current and Pending Support

REDACTED

Harry P. Warren
Co-Investigator

Astrophysicist
Smithsonian Astrophysical Observatory

Education

Ph.D., Plasma Physics, 1994, Columbia University
B.S., Physics, 1989, College of William and Mary

Background

Dr. Warren's research interests include the structure and dynamics of the solar corona and transition region, the solar EUV irradiance and its variability, and solar flares. Dr. Warren has extensive experience with data from the SoHO, TRACE, and Yohkoh missions. He is the author or co-author of 36 papers in the peer-reviewed literature and has been the principal investigator of three NASA grants for the analysis of solar observations.

Role on AIA

Dr. Warren will participate in instrument design and scientific planning for the mission, help coordinate co-observing programs with other observatories, and analyze data from the mission. He will calculate instrumental response to thermal plasma, assist in the development of differential emission measure tools, and work on the inter-calibration of the SDO/SIE and AIA.

Current and Pending Support

REDACTED

N.O. Weiss
Co-Investigator

Education

University of Cambridge, England
Sc.D., 1993.
Ph.D., Department of Geodesy and Geophysics, 1962.
M.A., 1961.
B.A., Natural Sciences Tripos I, Physics II, Clare College, 1957.

Professional Employment

Visiting Professor, Department of Applied Mathematics, University of Leeds, 2001 - present
President of the Royal Astronomical Society, 2000 - 02
Chairman, School of Physical Sciences, University of Cambridge, 1993 - 98
Fellow of the Royal Society, 1992
SERC Senior Fellow, 1987 - 92
Visiting Professor, School of Mathematical Sciences, Queen Mary and Westfield College, University of London, 1986 - 96
Reader in Astrophysics, University of Cambridge, 1979 - 87
Tutor for Graduate Students, Clare College, 1970 - 73
Director of Studies in Mathematics, Clare College, 1966 - 79
University Lecturer, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, 1965 - 79
Research Associate, UKAEA Culham Laboratory, 1962 - 65

Background

Performs research in the area of solar magneto-convection modeling.

Role on AIA

Dr. Weiss will participate in theoretical studies and modeling in support of the AIA investigation.

Current and Pending Support

REDACTED

C. Jacob Wolfson
Co-Investigator

Physicist, Consultant
Lockheed Martin Advanced Technology Center

Education

Ph.D., Physics, University of Utah, 1966. Thesis: High-Energy Meson Production Implications from Observing the Cosmic Ray Lunar Shadow

B.S. (with honors), Mathematics and Physics, Grinnell College, 1960

Background

Performs research in solar physics with emphasis on space flight instrumentation. Co-Investigator on the following NASA satellite programs: MXRH on OSO-8, XRP on SMM, CIP on OSL, SOI-MDI on SOHO, TRACE, and SECCHI on STEREO. Program Manager on MXRH, CIP, MDI, and TRACE; and Deputy PI on XRP for several of its operational years.

Role on AIA

Participate in sharpening the instrumental requirements, and provide advice on all aspects of program management and systems engineering. Participate in planning for, and conducting, mission operations. Play an active role in coordinating AIA with the other SDO investigations, especially HMI if the Stanford-led proposal is selected.

Current and Pending Support

REDACTED

Jean-Pierre Wülser
Co-Investigator

Education
Ph.D., Physics, University of Bern (Switzerland), 1988
M.S., Physics, University of Bern (Switzerland), 1984.

Professional Employment
Lockheed Martin Solar and Astrophysics Laboratory, 1995 – present
Institute for Astronomy, University of Hawaii, 1988 - 1995

Background
Background in solar physics research and instrument development. Developed a CCD imaging spectrograph at the University of Bern and used it to study flare energy transport. As a member of the Yohkoh team, analyzed coordinated X-ray observations from Yohkoh, and optical and magnetic observations from Mees Solar Observatory. Participated in the operations of the Yohkoh mission, served as the instrument scientist for the Mees CCD imaging spectrograph, and developed the Mees White Light Telescope. Participates in several XUV instrument development programs at Lockheed Martin, including GOES-SXI and STEREO-SECCHI. Currently instrument scientist for the SECCHI EUVI. Member of the American Astronomical Society, and the International Astronomical Union.

AIA Research Interests and Investigation Role
Participate in formulating the optical instrument design in close collaboration with SAO. Participate in planning for, and conducting mission operations, and coordination with observations from the extended STEREO mission. Research interests focus on understanding the dynamics of transient solar phenomena, and the relationship between plasma motions and the energy release process. Interested in the question, whether a common physical process can describe a broader range of transient phenomena including flares and coronal mass ejections.

Current and Pending Support

REDACTED

Intentionally blank

G2. STATEMENTS OF COMMITMENT

Attached are signed statements of commitment acknowledging Co-I participation in the AIA investigation. Where noted, the reference to “Multi-telescope Array for the Global Investigation of the Corona” (MAGIC) should be replaced with AIA. Missing statements of commitment may be submitted under separate cover.

Intentionally blank

Lockheed Martin
Advanced Technology Center
3251 Hanover Street Palo Alto, California 94304-1191

LOCKHEED MARTIN

April 8, 2002

Dr. Alan Title
Lockheed Martin
Advanced Technology Center
3251 Hanover Street
Palo Alto, California 94304-1191

Dear Alan:

We acknowledge that we are identified by name as Co-Investigators to the investigation entitled Atmospheric Imaging Assembly (AIA) that is submitted by Dr. A. M. Title to the Solar Dynamics Observatory (SDO) and Related Missions of Opportunity NASA Research Announcement, and that we intend to carry out all responsibilities identified for us in this proposal. We understand that the extent and justification of our participation as stated in this proposal will be evaluated during peer review in determining the merits of this proposal.

Sincerely,

B. De Pontieu	C. Schrijver
S. Fuselier	Richard A. Shine R. Shine
N. Hurlburt	Theodore Tarbell T. Tarbell
J. R. Lemen J. Lemen	C. Jacob Wolfson C. Wolfson
T. Metcalf	J. P. Wuelser J. Wuelser
Nariaki Nitta N. Nitta	

MONTANA STATE UNIVERSITY
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College of Letters and Science
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Bozeman, MT 59717-3840

P.C.H. Martens, Associate Research Professor
Telephone 406-994-7049
FAX 406-994-4452
Email martens@physics.montana.edu
http://solar.physics.montana.edu/martens/

March 28, 2002

Dr. A.M. Title,
Lockheed-Martin Advanced Technology Center
Dept. L9-41, Bldg. 252
3251 Hanover St.
Palo Alto, CA 94304

Dear Alan,

We acknowledge that we are identified by name as Co-Investigators to the investigation entitled *Atmospheric Imaging Assembly* (AIA) that is submitted by Dr. A. M. Title to the Solar Dynamics Observatory (SDO) and Related Missions of Opportunity NASA Research Announcement, and that we intend to carry out all responsibilities identified for us in this proposal. We understand that the extent and justification of our participation as stated in this proposal will be evaluated during peer review in determining the merits of this proposal.

Yours sincerely,

Prof. P.C.H. Martens

David McKenzie

Dr. D.E. McKenzie

Solar Observatories Group
Stanford University

W. W. Hansen Experimental Physics Laboratory
455 Via Palou, Stanford, CA 94305-4085
650-723-1505 Fax: 650-725-2333

3 April 2002

Dr. Alan M. Title
Lockheed Martin Advanced Technology Center
Dept. H112, Bldg. 252
3251 Hanover St.
Palo Alto, CA 94304

Dear Alan:

We acknowledge that we are identified by name as Co-Investigators to the investigation entitled "Atmospheric Imaging Assembly (AIA)" that is submitted by Alan M. Title to the Solar Dynamics Observatory (SDO) NASA Research Announcement 02-OSS-01, and that we intend to carry out all responsibilities identified for us in this proposal. We understand that the extent and justification of our participation as stated in this proposal will be evaluated during peer review in determining the merits of this proposal.

Sincerely,

Philip H. Scherrer

Rock I. Bush

Alexander G. Kosovichev

NSO
National Solar Observatory

Dr. Christoph U. Keller
950 N. Cherry Avenue
Tucson, AZ 85719
Ph. (520) 318-8445 Fax (520) 318-8278 e-mail: *ckeller@noao.edu*

March 28, 2002

Dear Alan,

I acknowledge that I am identified by name as Co-Investigator to the investigation entitled *Atmospheric Imaging Assembly (AIA)* that is submitted by Dr. A. M. Title to the *Solar Dynamics Observatory (SDO) and Related Missions of Opportunity* NASA Research Announcement, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be evaluated during peer review in determining the merits of this proposal.

Christoph Keller

C. U. Keller

CUA

THE CATHOLIC UNIVERSITY OF AMERICA

Department of Physics
Washington, D.C. 20064
202-319-5315 • Fax: 202-319-4448
www.acad.cua.edu/iacs/

March 29, 2002

Dr. Alan M. Title
Lockheed Martin Solar and Astrophysics Laboratory
3251 Hanover Street
Palo Alto, CA 94304

Dear Alan:

I acknowledge that I am identified by name as a Co-Investigator to the investigation entitled *Atmospheric Imaging Assembly (AIA)* that is submitted by Dr. A. M. Title to the *Solar Dynamics Observatory (SDO) and Related Missions of Opportunity* NASA Research Announcement, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be evaluated during peer review in determining the merits of this proposal.

Sincerely,

Jeffrey W. Brosius

Jeffrey W. Brosius

National Aeronautics and
Space Administration
Goddard Space Flight Center
Greenbelt, MD 20771

Reply to Attn of: 682

Dr. Alan Title
Lockheed Martin Solar and Astrophysics Laboratory
3251 Hanover Street
Palo Alto, CA 94304

Dear Dr. Title:

I acknowledge that I am identified by name as a Co-Investigator in the investigation entitled "Atmospheric Imaging Assembly" that will be submitted by you, as Principal Investigator, in response to the NASA Announcement of Opportunity AO-02-OSS-01 (Solar Dynamics Observatory and Related Missions of Opportunity). I intend to carry out all responsibilities identified for me in this proposal, and I understand that the extent and justification of my participation as stated in the proposal will be evaluated during peer review in determining the merits of the proposal.

Sincerely,

Joseph B. Gurman
Solar Physics Branch, Code 682
Laboratory for Astronomy and Solar Physics

National Aeronautics and
Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Reply to Attn of:

8 April 2002

Dear Alan,

I acknowledge that I am identified by name as Co-Investigator to the AIA investigation that is submitted by Dr. A. M. Title to the *Solar Dynamics Observatory (SDO) and Related Missions of Opportunity* NASA Research Announcement, and that I intend to carry out all responsibilities identified for us in this proposal. I understand that the extent and justification of our participation as stated in this proposal will be evaluated during peer review in determining the merits of this proposal.

G. Allen Gary

G. Allen Gary

(Allen.Gary@msfc.nasa.gov)
SD50-Solar Physics Team
(NSSTC Rm. 2039)
Space Science Department
Science Directorate
Marshall Space Flight Center / NASA
Huntsville, AL 35812 USA
(256) 961-7609 Fax:(256) 961-7291

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Science Applications International Corporation
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1 April 2002

Dear Alan,

I acknowledge that I am identified by name as Co-Investigator to the investigation entitled *Atmospheric Imaging Assembly (AIA)* that is submitted by Dr. A. M. Title to the *Solar Dynamics Observatory (SDO) and Related Missions of Opportunity* NASA Research Announcement, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be evaluated during peer review in determining the merits of this proposal.

Zoran Mikić

Zoran Mikić

10260 Campus Point Drive, San Diego, CA 92121-1578 (858) 826-6000

SOUTHWEST RESEARCH INSTITUTE
Instrumentation and Space Research Division • 1050 Walnut St., Suite 426 • Boulder, CO 80302
(303) 546-9670 • FAX (303) 546-9687 • http://www.boulder.swri.edu

9 April 2002

Dear Alan,

I acknowledge that I am identified by name as a Co-Investigator to the investigation entitled *Multi-telescope Array for the Global Investigation of the Corona (MAGIC)* that is submitted by Dr. A. M. Title to the *Solar Dynamics Observatory (SDO) and Related Missions of Opportunity* NASA Research Announcement, and that I intend to carry out all responsibilities identified for us in this proposal. I understand that the extent and justification of our participation as stated in this proposal will be evaluated during peer review in determining the merits of this proposal.

Don Hassler

Dr. Donald M. Hassler

UNIVERSITY COLLEGE LONDON
DEPARTMENT OF SPACE & CLIMATE PHYSICS
MULLARD SPACE SCIENCE LABORATORY

Holmbury St. Mary
Dorking
SurreyRH5 6NT
United Kingdom

Telephone: +44 (0) 1483 274111
Facsimile: +44 (0) 1483 278312
email: jlc@mssl.ucl.ac.uk

27th March, 2002

Dr Alan M. Title,
Director of Research,
Lockheed Martin ATC,
Dept L9-41, Building 252,
3251, Hanover Street,
Palo Alto,
CALIFORNIA 94304.

Dear Alan,

We acknowledge that we are identified by name as Co-Investigators to the investigation entitled *Atmospheric Imaging Assembly (AIA)* that is submitted by Dr. A. M. Title to the *Solar Dynamics Observatory (SDO) and Related Missions of Opportunity* NASA Research Announcement, and that we intend to carry out all responsibilities identified for us in this proposal subject to the availability of UK funding. We understand that the extent and justification of our participation as stated in your proposal will be evaluated during peer review in determining the merits of the proposal.

Yours sincerely

J.L. Culhane

L. K. Harra

Space Science and Technology Dept
Rutherford Appleton Laboratory
Chilton, Didcot, OX11 0QX
United Kingdom

E-mail: A.Fludra@rl.ac.uk

April 10, 2002

Dear Alan,

I acknowledge that I am identified by name as Co-Investigator to the investigation entitled *Atmospheric Imaging Assembly (AIA)* that is submitted by Dr. A.M. Title to the *Solar Dynamics Observatory (SDO) and Related Missions of Opportunity* NASA Research Announcement, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be evaluated during peer review in determining the merits of this proposal.

Andrzej Fludra

Dr. Andrzej Fludra

CLRC

SPACE SCIENCE DEPARTMENT

Rutherford Appleton Laboratory
Chilton Didcot
Oxfordshire
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Telephone +44 (0)1235-44-6550
Fax +44 (0)1235-44-5848
E-mail: n.r.waltham@rl.ac.uk

Dr A Title
Lockheed Martin Corp.,
3251 Hanover St,
Palo Alto, CA
USA

April 18, 2002

Dear Alan,

AIA Proposal for SDO

I acknowledge that I am identified by name as Co-Investigator to the investigation entitled

"Atmospheric Imaging Assembly (AIA)"

that is submitted by Dr. A Title to the NASA AO 02-OSS-01 "Solar Dynamics Observatory (SDO) and Related Missions of Opportunity" Research Announcement, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be evaluated during peer review in determining the merits of this proposal.

Yours sincerely,

N. R. Waltham

Dr Nick Waltham

Head of Imaging Systems Division, Rutherford Appleton Laboratory esa

MEMO

date/*date*	10 April 2002	ref./*réf.*	SH/bf/02105	page/*page*	1/1
from/*de*	Bernhard Fleck (SCI-SH)	visa/*visa*			
to/*à*	Alan Title (LMSAL)	copy/*copie*			

subject/*objet* **AIA/SDO**

Dear Alan,

I acknowledge that I am identified by name as Co-Investigator to the investigation entitled *Atmospheric Imaging Assembly (AIA)* that is submitted by Dr. A. M. Title to the *Solar Dynamics Observatory (SDO) and Related Missions of Opportunity* NASA Research Announcement, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be evaluated during peer review in determining the merits of this proposal.

Sincerely,

Bernhard Fleck
SOHO Project Scientist

European Space Agency
Agence spatiale européenne

SOHO Project Scientist Office
NASA/GSFC Mailcode 682.3 Greenbelt, MD 20771
Tel: (301) 286-4098 Fax: (301) 286-0264

Niels Bohr Institute for Astronomy, Physics and Geophysics
University of Copenhagen

Juliane Maries Vej 30
DK-2100 København Ø

Dr. A.M. Title
LMSAL
Palo Alto, Ca
USA

April 9, 2002

Dear Alan,

I acknowledge that I am identified by name as a Co-Investigator to the investigation entitled *Multi-telescope Array for the Global Investigation of the Corona (MAGIC)* that is submitted by you to the *Solar Dynamics Observatory (SDO) and Related Missions of Opportunity* NASA Research Announcement, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be evaluated during peer review in determining the merits of this proposal.

Å. Nordlund

Åke Nordlund

Astronomical Observatory / NBIfAFG
University of Copenhagen

Åke Nordlund Tel.:: +45 3532 5968 / +45 2145 4983 email:aake@astro.ku.dk

G3. LETTERS OF ENDORSEMENT

Attached are signed letters of endorsement from all organizations offering to supply goods or services, or otherwise make a contribution to the AIA investigation. Where noted, the reference to “Multi-telescope Array for the Global Investigation of the Corona” (MAGIC) should be replaced with AIA. Signed letters of support or commitment to or involvement in the education and public outreach effort are also included.

Intentionally blank

Smithsonian Astrophysical Observatory

4 April 2002

Mr. Robert Patterson
Lockheed Martin Space Systems Company
Missiles and Space Operations
Advanced Technology Center
Orgn. EG-26, Bldg. 201
3251 Hanover Street
Palo Alto, California 94304-1191

Dear Mr. Patterson:

The Smithsonian Institution Astrophysical Observatory (SAO), in response to your Request for Proposal dated 8 March 2002, is pleased to submit the attached Proposal P5328-4-02 for an eleven (11) month Cost Reimbursement (No Fee) Research and Development Contract with Nonprofit Organizations in the amount of $1,125,115 for MAGIC: The Solar Dynamics Observatory's Atmospheric Imager that could commence on 15 September 2002 and continue through 8 August 2003.

A Rough Order of Magnitude (ROM) cost for the period 9 August 2003 through 30 September 2013 in the amount of $20,129,000 is listed by Fiscal Year.

The program will be conducted by the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts. The program will be performed under the direction of Dr. Leon Golub, as the Principal Investigator, within the High Energy Astrophysics Division, with Dr. Stephen Murray as the Associate Director of the Division.

Inquiries of a technical nature should be directed to Dr. Leon Golub, Mail Stop 58, Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge, Massachusetts 02138-1516, telephone (617) 495-7177. Inquiries and documents of a contractual nature should be directed to Mr. William J. Ford, Mail Stop 23, 60 Garden Street, Cambridge, Massachusetts 02138-1516, telephone (617) 495-7317, or e-mail wford@cfa.harvard.edu.

Sincerely yours,

Irwin Shapiro

Irwin Shapiro
Director

JGH/cm
Enclosures (4)

SMITHSONIAN INSTITUTION
60 Garden Street
Cambridge MA 02138-1516
617.495.7000 Telephone

UNIVERSITY COLLEGE LONDON
DEPARTMENT OF SPACE & CLIMATE PHYSICS
MULLARD SPACE SCIENCE LABORATORY

Holmbury St. Mary
Dorking
SurreyRH5 6NT
United Kingdom

Telephone: +44 (0) 1483 274111
Facsimile: +44 (0) 1483 278312
email: jlc@mssl.ucl.ac.uk

27th March, 2002.

Dr Alan M. Title,
Director of Research,
Lockheed Martin ATC,
Dept L9-41, Building 252,
3251, Hanover Street,
Palo Alto,
CALIFORNIA 94304.

Dear Dr. Title,

The Mullard Space Science Laboratory of University College London acknowledges the identification of Len Culhane and Louise K. Harra as Co-Investigators to the investigation entitled " *Atmospheric Imaging Assembly (AIA)*" that is being submitted by you in response to NASA Research Announcement 02-OSS-01. The Mullard Space Science Laboratory will support the work that results from the responsibilities of Len Culhane and Louise Harra within this proposal subject to the availability of funding within the UK. I understand that there will be no exchange of funds between the US and the UK for the activities of the Mullard Space Science Laboratory that are related to this proposal.

Yours sincerely

J. Len Culhane

Professor J.L. Culhane, FRS
Director, MSSL and
Head, Department of Space and Climate Physics

CLRC

SPACE SCIENCE & TECHNOLOGY DEPARTMENT

Rutherford Appleton Laboratory
Chilton Didcot
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LMSAL
3251 Hanover Street
Palo Alto
CA 94304
USA

Direct line +44 (0)1235 445527
Local fax +44 (0)1235 446640
E-mail r.holdaway@rl.ac.uk

27th March 2002

Dear Dr Title

MAGIC PROPOSAL FOR SDO

With this letter I wish to endorse the participation of Professor Richard Harrison, Dr Andrzej Fludra and Dr Nick Waltham on the MAGIC investigation, which is submitted in response to the NASA AO 02-OSS-01 Research Announcement "Solar Dynamics Observatory (SDO) and Related Missions of Opportunity".

The Space Science and Technology Department of the Rutherford Appleton Laboratory is committed to providing the support described in the MAGIC proposal. The RAL Co-Investigators will carry out all responsibilities identified for them in the proposal. However, it is understood that the extent and justification of this participation will be evaluated during peer review in determining the merits of the proposal, and are also subject to peer review for funding in the UK.

Yours sincerely

Richard Holdaway

Prof. Richard Holdaway FREng
Director

PPARC

The UK's Strategic Science Investment Agency

Particle Physics and Astronomy Research Council
Polaris House, North Star Avenue, Swindon
Wiltshire SN2 1SZ United Kingdom

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Dr ~~Alan Title~~ J Wolfson
Building 252
Lockheed Martin ATC
3251 Hanover Street
Palo Alto
CA 94304
USA

Direct line (01793) 442046
Local fax (01793) 442036
E-mail Sue_Horne@pparc.ac.uk
Our Ref PP/CA/302
Your Ref

17 April, 2002

Dear Dr Title

Solar Dynamics Observatory (SDO) and Related Missions of Opportunity (NRA NO: 02-OSS-01)

TITLE OF PROPOSAL: MAGIC
UK PARTICIPANT: MULLARD SPACE SCIENCE LABORATORY
RUTHERFORD APPLETON LABORATORY

I am pleased to confirm that PPARC has given the necessary preliminary endorsement to the scientific contents of the UK element of the above proposal. The PPARC endorsement does not guarantee any provision for future financial support. Any application to us for funding will be considered separately.

Yours sincerely

Sue Horne

Sue Horne (Mrs)
Head of Solar System and Space Science Group
Astronomy Division

cc: Dr J Wolfson, Lockheed Martin ATC
Professor J L Culhane, MSSL
Dr R Harrison, RAL

Date: Fri, 19 Apr 2002 12:33:36 -0700
From: Deborah Scherrer <deborah@quake.Stanford.EDU>
To: bdp@lmsal.com
Subject: letter of commitment

Dr. Alan Title
Lockheed Martin Advanced Technology Center
Dept. H112, Bldg. 252
3251 Hanover St.
Palo Alto, CA 94304

Dear Dr. Title:

I acknowledge that I am identified as an E/PO participant in the investigation entitled "Atmospheric Imaging Assembly" that is being submitted to the Solar Dynamics Observatory (SDO) NASA Research Announcement 02-OSS-01. I am looking forward to collaborating with the AIA team and intend to carry out all responsibilities identified for me in this proposal.

Sincerely,
Deborah K. Scherrer
Coordinator, Stanford Solar Center
Stanford University

chabot
space & science center

Dr. Alan Title
Lockheed Martin Advanced Technology Center
Dept. H112, Bldg. 252
3251 Hanover St.
Palo Alto, CA 94304

April 12, 2002

Dear. Dr. Title;

The Chabot Space and Science Center acknowledges that we are identified as an E/PO partner in the investigation entitled "Atmospheric Imaging Assembly" that is being submitted to the Solar Dynamics Observatory (SDO) NASA Research Announcement 02-OSS-01. We are looking forward to collaborating with the AIA team and intend to carry out all responsibilities identified for us in this proposal.

We understand there will be no exchange of funds in this program.

Sincerely,

Dwayne A. Oslund

Dwayne A. Oslund
Associate Executive Director

10000 Skyline Boulevard
Oakland, California 94619
Phone: 510.336.7300
Fax: 510.336.7491
www.chabotspace.org

In association with the Smithsonian Institution

LHS★

Lawrence Hall of Science
University of California
Berkeley, CA 94720-5200

Telephone: 510-643-5082
FAX: 510-642-1055
agould@uclink4.berkeley

April 11, 2002

Dr. Alan Title
Lockheed Martin Solar and Astrophysics Laboratory
3251 Hanover Street
Palo Alto, CA 94304 USA

Dear Dr. Title:

The Lawrence Hall of Science acknowledges that we are identified as an E/PO partner in the investigation entitled "Atmospheric Imaging Assembly" that is being submitted to the Solar Dynamics Observatory (SDO) NASA Research Announcement 02-OSS-01. We are looking forward to collaborating with the AIA team and intend to carry out all responsibilities identified for us in this proposal.

We wish you best of luck in obtaining funds for this mission, and are looking forward to working with you.

Sincerely,

Alan Gould

Alan Gould
Project Director
Lawrence Hall of Science

I^iiSE

Institute for Imagination and Innovation in Science Education
Educational Communities linking students, parents, educators, and industry to create Pathways to Success
440 Dixon Landing Rd. • Suite H301 • Milpitas, CA 95035 – (510) 723-6881

Dr. Alan Title
Lockheed Martin Advance Technology Center
Dept. H112, Bldg. 252
3251 Hanover St.
Palo Alto, CA 94304

Dear Dr. Title,

The Institute for Imagination and Innovation in Science Education (I^iiSE) is most happy to acknowledge our association with you and to be identified as an E/PO partner in the investigation entitled "Atmospheric Imaging Assembly" that is being submitted to the Solar Dynamics Observatory (SDO) NASA Research Announcement 02-OSS-01.

Needless to say, we are anxiously looking forward to collaboration with the AIA team and intend to carry out all responsibilities identified for us in this proposal. We understand the will be no exchange of funds in this program. However, our association with your team and the education benefits for students in K-14, parents, and teachers we serve will be tremendous.

Again, thanks so much for including our organization in your plans. We look forward to the great success of our association.

Sincerely,

Timothy A. Dave
I^iiSE Board Chairman
Professor of Astronomy and Physics
Chabot College

CALIFORNIA ACADEMY OF SCIENCES™
GOLDEN GATE PARK

April 16, 2002

Dr. Alan Title
Lockheed Martin Advanced Technology Center
Dept. H112, Bldg. 252
3251 Hanover St.
Palo Alto, CA 94304

Dear Dr. Title:

The Morrison Planetarium acknowledges that we are identified as an E/PO partner in the investigation entitled "Atmospheric Imaging Assembly" that is being submitted to the Solar Dynamics Observatory (SDO) NASA Research Announcement 02-OSS-01. We are looking forward to collaborating with the AIA team and intend to carry out all responsibilities identified for us in this proposal. We understand there will be no exchange of funds in this program.

Sincerely,

Bing F. Quock
Assistant Chairman
Morrison Planetarium
California Academy of Sciences

TheTech

Dr. Alan Title
Lockheed Martin Advanced Technology Center
Dept. H112, Bldg. 252
3251 Hanover St.
Palo Alto, CA 94304

April 11, 2002

Dear Dr. Title:

The Tech Museum Center for Public Policy acknowledges that we are identified as an E/PO partner in the investigation entitled "Atmospheric Imaging Assembly" that is being submitted to the Solar Dynamics Observatory (SDO) NASA Research Announcement 02-OSS-01. We are looking forward to collaborating with the AIA team and intend to carry out all responsibilities identified for us in this proposal. We understand there will be no exchange of funds relating to this proposal.

Sincerely,

Claire Holland

Claire Holland
Programs Manager

The Tech
Museum of Innovation
201 South Market St.
San Jose, CA 95113-2008
408 294 TECH
Fax 408-279-7167
http://www.thetech.org

chabot
space & science center

Dr. Alan Title
Lockheed Martin Advanced Technology Center
Dept. H112, Bldg. 252
3251 Hanover St.
Palo Alto, CA 94304

April 12, 2002

Dear. Dr. Title;

The Chabot Space and Science Center acknowledges that we are identified as an E/PO partner in the investigation entitled "Atmospheric Imaging Assembly" that is being submitted to the Solar Dynamics Observatory (SDO) NASA Research Announcement 02-OSS-01. We are looking forward to collaborating with the AIA team and intend to carry out all responsibilities identified for us in this proposal.

We understand there will be no exchange of funds in this program.

Sincerely,

Dwayne A. Oslund
Associate Executive Director

10000 Skyline Boulevard
Oakland, California 94619
Phone: 510.336.7300
Fax: 510.336.7491
www.chabotspace.org

In association with the Smithsonian Institution

Haas Center for Public Service

Stanford University

Nadinne Cruz
Director
(650) 723-4662 direct/vox
(650) 736-1649 fax
nadinne@stanford.edu

April 19, 2002

Dr. Alan Title
Lockheed Martin Advanced Technology Center
Dept. H112, Bldg. 252
3251 Hanover St.
Palo Alto, CA 94304

Dear Dr. Title:

The Haas Center for Public Service acknowledges that we are identified as an E/PO partner in the investigation entitled "Atmospheric Imaging Assembly" that is being submitted to the Solar Dynamics Observatory (SDO) NASA Research Announcement 02-OSS-01. We are looking forward to collaborating with the AIA team and intend to carry out all responsibilities identified for us in this proposal.

Sincerely,

Nadinne Cruz

Nadinne Cruz
Director

Montana Space Grant Consortium

261 EPS Building
Montana State University
P.O. Box 173835
Bozeman, MT 59717-3835

(406) 994-4223 (Voice) • (406) 994-4452 (Fax)
msgc@montana.edu • www.montana.edu/wwwmsgc/

April 18, 2002

To whom it may concern,

The Montana Space Grant Consortium is pleased to have the opportunity to collaborate with the SDO/AIA team consisting of Lockheed-Martin Solar & Astrophysics Lab, Stanford University, Montana State University, and Smithsonian Astrophysical Observatory. We enthusiastically support the Education/Public Outreach component of the mission, and look forward to contributing to it.

Sincerely,

William A. Hiscock
Director

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G4 STATEMENT OF WORK

This Appendix contains a draft Statement of Work (SOW) for Phases A-E of the AIA Program. This program is a collaboration between the Lockheed Martin Solar and Astrophysical Laboratory (LMSAL) and the Smithsonian Astrophysical Observatory (SAO). This SOW is divided into three sections describing Phase A, Phases B/C/D, and Phase E.

PHASE A – CONCEPT DEFINITION

Scope

LMSAL will develop the AIA concept to the level where detailed mission, science, and instrument development are defined, and spacecraft interfaces and allocations determined. This will permit the establishment of firm costs for all subsequent phases. In addition to SAO, LMSAL will work in collaboration with the Mullard Space Sciences Laboratory (MSSL) and the Rutherford Appleton Laboratory (RAL) in their definition of the CCD's and cameras, respectively for this mission. Phase A will culminate with a study report of the effort and a cost proposal for all subsequent phases.

Deliverables

- Monthly Progress Reports
- Final Report
  - Executive Summary
  - Science Investigation
  - Implementation Plan
    - Organization
    - Responsibilities
    - Key Personnel
    - Subcontracting Approach
    - Schedules
    - Risk Management
    - Reporting and Reviews
    - Instrument Design
    - Instrument Fabrication
    - Instrument Testing/Calibration
    - PAIP
    - Interface Definitions
    - Technical Readiness Level Status
    - E/PO
- Preparation for and support of
  - Systems Requirements Review
  - Initial Confirmation Review
- Cost Proposal for Phases B-E

Government Responsibilities

- Establish a Letter of Agreement between the UK and USA
  - MSSL
  - RAL

PHASE B/C/D – DESIGN & IMPLEMENTATION

Scope

LMSAL, with a significant contribution from SAO will perform a preliminary design, detailed design, and fabricate, test and commission the AIA instrument.

The preliminary design activities will include, but not be limited to, defining both internal and external interfaces, conducting the systems engineering and performance analysis, develop preliminary test plans, define the GSE, and establish the operational concept. Updated and refined schedules for the implementation phase will be established. The project team will work with NASA to establish a comprehensive education and public outreach program.

The detailed design activities will bring the design to the point where fabrication and procurement activities can start. An instrument integration plan will be developed and the GSE design will be completed. The flight and GSE software architecture will be completed and code implementation initiated.

The implementation phase will commence with the fabrication and procurement of all hardware elements. All of the subsystems will be integrated. This includes the telescopes provided by SAO, the camera from RAL, and the CCDs from MSSL. Test procedures will be developed from the test plans and all flight hardware will be fully tested to the specified requirements established in the instrument performance specification. Instrument calibrations will be performed. The instrument team will support the launch and the subsequent 30 days of on-orbit commissioning, culminating in the completion of this mission phase.

Deliverables

- Preparation for and support of:
  - Preliminary Design Review
  - Confirmation review/Non-Advocate Review
  - Critical Design Review
  - Pre-Environmental Review
  - Pre-Ship Review
  - Mission Readiness Review
  - Flight Readiness Review
  - Launch Readiness Review
  - Flight Operations Review
  - Mission Operations Review
- Monthly Reports
  - Progress Report
  - Financial Report
  - Schedules
- Other Reports
  - Education and Public Outreach Report
  - Parts and Materials List
  - Contamination Control Plan
  - Software Development plan
  - Complete Set of Drawings
  - Verification Plan
  - Test Plan
  - Test Procedures
  - Instrument Specification
  - Mission Operations Plan
  - Data Analysis Plan
  - Science Preparation Summary
- Other Items
  - STM
  - Flight Instrument
  - Flight and GSE Software
  - GSE
- Government Responsibilities
  - Augment the letter of Agreement between the UK and USA to include
    - St. Andrews
    - Cambridge University
- Establish a Letter of Agreement between the Netherlands and the USA
  - ESTEC
  - Establish a Letter of Agreement between Denmark and the USA
- Copenhagen Observatory
- Establish a Letter of Agreement between Sweden and the USA
  - Swedish Solar Observatory
- Establish a Letter of Agreement between France and the USA
  - Meudon

PHASE E – MISSION OPERATIONS

Scope

The AIA team will support mission operations, data reduction, and data analysis activities for the five year period starting 30 days after launch, and data analysis for a sixth year The data will be processed and archived. The health and safety of the AIA instrument will be monitored, and on-orbit performance affecting scientific analysis will be characterized.

Deliverables

- Publications in Scientific Journals
- Preparation of Data for Public Use
- Calibrated Data Sets for NASA Archiving
- Education and Public Outreach Report
- Monthly Reports
  - Progress Report
  - Financial Report

Government Responsibilities

No additional elements

G5. REFERENCES

[1] C. J. Schrijver, A. M. Title, T. E. Berger, L. Fletcher, N. E. Hurlburt, R. Nightingale, R. A. Shine, T. D. Tarbell, J. Wolfson, L. Golub, J. A. Bookbinder, E. E. DeLuca, R. A. McMullen, H. P. Warren, C. C. Kankelborg, B. N. Handy, and B. De Pontieu. A new view of the solar outer atmosphere by the Transition Region and Coronal Explorer. *SPh*, 187:261--302, 1999.

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G5. ACRONYMS

3-D	three-dimensional
ADC	analog to digital converter
AEC	automatic exposure control
AECA	Arms Export Control Act
AGU	American Geophysical Union
AI	associate investigator
AIA	Atmospheric Imaging Assembly
AIRO	American Indian Research Opportunities
AIS	Atmospheric Imaging Spectrograph
AO	Announcement of Opportunity
ASIC	application specific integrated circuit
ASTM	American Society for Testing and Materials
ATC	Advanced Technology Center (LM)
ATST	Advanced Technology Solar Telescope
BBSO	Big Bear Solar Observatory
BOL/EOL	beginning of life/end of life
BSI	British Standards Institute
CAS	California Academy of Sciences
CCD	charge coupled device
CDR	critical design review
CDS	coronal diagnostic spectrometer
CME	coronal mass ejections
Co-I	co-investigator
CPS	Corporate Policy Statement
CR	Confirmation Review
CSE	chief systems engineer
CVCM	collected volatile condensable materials
DEM	differential emission measure
DoD	Department of Defense
E/PO	Education and Public Outreach
ECLPS	Export/Import Compliance and License Processing System
EDAC	error detection and correction
EDCS	Export Document Control System
EEE	electrical, electronic, and electromechancical
EILC	Export/Import Licensing & Compliance
EILCO	Export/Import Licensing & Compliance Office
EIS	EUV Imaging Spectrometer

EIT	Extreme UV Imaging Telescope
ELV	expendable launch vehicle
EMI	electromagnetic interference
EP	equivalent people
ESA	European Space Agency
ESTEC	European Space Research & Technology Center
EUV	extreme ultraviolet
EVM	earned value measurement
FAQ	frequently asked questions
FAR	Federal Acquisition Regulations
FASR	Frequency Agile Solar Radiotelescope
FOV	field of view
FPGA	field programmable gate array
FTE	full-time equivalent
FWHM	full width and half maximum
FY	fiscal year
GEC	Geospace Electrodynamic Connections
GEMS	Great Expectations in Math and Science
GEVS-SE	General Environmental Verification Specification for STS ad ELV
GIDEP	Government Industry Data Exchange Program
GMDT	Geospace Mission Definition Team
GOES	Geostationary Operational Environmental Satellite
GONG	Global Oscillations Network Group
GPMC	Goddard Program Management Council
GSE	ground support equipment
GSFC	Goddard Space Flight Center
GT	guide telescope
GUI	graphical user interface
H(V)MI	Helioseismic (and Vector) Magnetic Imager
HDTV	high definition television
HEAD	High Energy Astrophysics Division
I&T	integration and test
ICD	interface control document
ICR	Initial Confirmation Review
IDL	interactive data language
IIISE	Institute for Imagination and Innovation in Science Education
ILWS	International Living With a Star
IMAGE	Imager for Magnetopause-to-Aurora Global Exploration

IMAR	Instrument Mission Assurance Requirements
IPS	Instrument Performance Specification
ISAS	Institute of Space and Astronautical Science
ISS	Image Stabilization System
ITAR	International Traffic in Arms Regulations
LASCO	Large Angle Spectroscopic Coronagraph
LED	light emitting diode
LLNL	Lawrence Livermore National Laboratory
LM	Lockheed Martin
LMATC	Lockheed Martin Advanced Technology Center
LMCEIO	Lockheed Martin Corporate Export/Import Office
LMS	License Management System
LMSAL	Lockheed Martin Solar and Astrophysics Laboratory
LMSSC	Lockheed Martin Space Systems Company
LMSSC-MSO	Lockheed Martin Space Systems Company-Missiles & Space Operations
M&P	materials and process
MA	mission assurance
MagCon	Magnetospheric Constellation
MAGIC	Multi-telescope Array for the Global Investigation of the Corona
MAR	Mission Assurance Requirements
MDI	Michelson Doppler Imager
MHD	magnetohydrodynamic
MK	mega Kelvin (10^6 K)
MLI	multilayer insulation (thermal blanket)
MMS	magnetospheric multi-scale
MO	Missions of Opportunity
MO&DA	mission operations & data analysis
MOC	mission operation center
MOU	Memorandum of Understanding
MSFC	Marshal Space Flight Center
MSGC	Montana Space Grant Consortium
MSSL	Mullard Space Science Laboratory
MSU	Montana State University
MURI	Multidisciplinary University Research Institute
NAR	Non-Advocate Review
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NPG	NASA Procedures and Guidelines

NPOESS	National Polar-Orbiting Environmental Satellite
NRE	non-recurring costs
NRT	near real-time
NSF	National Science Foundation
NSO	National Solar Observatory
NSTA	National Science Teachers Association
NVR	non-volatile residue
ODTC	Office of Defense Trade Controls
OSS	Office of Space Science
PAIP	Product Assurance Implementation Plan
PCB	parts control board
PDR	Preliminary Design Review
PI	principal investigator
PIT	Photometric Imaging Telescope
PM	project manager
PPARC	Particle Physics and Astronomy Research Council
QCM	quartz crystal microbalance
QE	quantum efficiency
RAL	Rutherford Appleton Laboratory
RGA	residual gas analyzer
RHESSI	Reuven Ramaty High Energy Solar Spectroscopic Imager
RICE	Compression scheme developed by Robert Rice
RISE	Radiative Inputs of the Sun to Earth
S/N	signal-to-noise
SAIC	Science Applications International Corporation
SAO	Smithsonian Astrophysical Observatory
SAT	Science Architecture Team
SBIR	Small Business Independent Research (program)
SBP	Small Business Program
SDB	Small Disadvantaged Business
SDO	Solar Dynamics Observatory
SDT	Science Definition Team
SEC	Sun-Earth Connection
SECAS	Sun-Earth Connection Advisory Subcommittee
SECCHI	Sun Earth Connection Coronal and Heliospheric Investigation
SECEF	SEC Education Forum
SED	Science Education Department
SET	Space Environment Testbed

SEU	Single event upset
SHINE	Solar Heliospheric Interplanetary Environment
SIE	Spectrometer for Irradiance in the EUV
SLISR	Stanford Lockheed Institute for Space Research
SMB	Small Minority Business
SOC	Science Operations Center
SOHO	Solar and Heliospheric Observatory
SOLIS	Synoptic Optical Long-term Investigations of the Sun
SONAR	SOlar Near-surface Activity-region Rendering
SORCE	SOlar Radiation and Climate Explorer
SOT-FFP	Solar Optical Telescope-Focal Plane Package
SOW	Statement of Work
SRB	square root binning (compression)
SRR	Systems Requirements Review
SScAC	Space Science Advisory Committee
SSP	Standard Software Process
STEREO	Solar Terrestrial Relations Observatories
STM	structural and thermal model
STP	Solar Terrestrial Probes
SUMER	Solar UV measurements of Emitted Radiation
SwRI	Southwest Research Institute
SXI	Solar X-ray Imager
SXT	Solar X-ray Telescope
TAA	Technical Assistance Agreements
TMCO	Technical, Management, Cost, and Other
TML	total mass loss
TR&T	Targeted Research & Technology
TRACE	Transition Region and Coronal Explorer
TRL	Technology Readiness Levels
TTCP	Technology Transfer Control Plans
UIS	UV/EUV Imaging Spectrograph
UK	United Kingdom
US	United States
UV	ultra-violet
VSO	Virtual Solar Observatory
WBS	work breakdown structure
WCI	White-light Coronagraphic Imager
XPS	XUV Photometer System

XRP	X-ray Polychromotor
XRT	X-ray Telescope
XUV	extreme UV
YPOP	Yohkoh Public Outreach Program

G6 DESCRIPTION OF TEAM MEMBER SELECTION (NASA PI'S ONLY)

Appendix G6 is not applicable for this AIA proposal.

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G7. TECHNICAL CONTENT OF ANY INTERNATIONAL AGREEMENTS

The following contains draft language for the technical content of the International agreement between NASA and PPARC (UK) for the AIA.

Dr. Graham Brooks
Particle Physics and Astronomy Research Council
Polaris House
North Star Avenue
Swindon Wiltshire SN2 1 SZ
United Kingdom

Dear Dr. Brooks:

The National Aeronautics and Space Administration (NASA) and the Particle Physics and Astronomy Research Council (PPARC) have a mutual interest in pursuing cooperation on the Atmosphere Imaging Assembly (AIA) of the Solar Dynamics Observatory (SDO) mission. The purpose of this letter is to establish an Agreement between NASA and PPARC (hereinafter, "the Parties") to address our cooperation on the SDO mission.

The SDO is the first Space Weather Research Network mission in the Living With a Star program for the National Aeronautics and Space Administration (NASA). Living With a Star (LWS) is managed by the Sun-Earth Connection Division of the Office of Space Science (OSS) within NASA. The LWS program sponsors the targeted basic research required to develop the scientific understanding necessary to effectively address those aspects of the coupled Sun-Earth system that directly affect life and society. SDO further derives from the strategic element called SOlar Near-surface Active-region Rendering (SONAR) in the OSS 2000 Sun-Earth Connection (SEC) Roadmap (see Appendix C for access to this and related documents). LWS generally and SDO in particular also present a singular opportunity for Education and Public Outreach (E/PO). NASA expect to fund the selected SDO investigations as the first mission of the LWS program, consistent with the recommendations of its LWS Science Architecture Team (SAT) the Sun-Earth Connection Advisory Subcommittee (SECAS), and Space Science Advisory Committee (SscAC) and the recent decadal study for astronomy and astrophysics by the National Research Council.

The Atmospheric Imaging Assembly (AIA) will characterize the rapid evolution of plasma in the chromosphere and lower corona and will help interpret the EUV spectral irradiance measurements, Simultaneous full-disk 1.2-arcsec resolution images of the solar atmosphere in several e=wavelengths spanning the temperature rage 20,000 to 4 million Kelvin (K) should be sufficient. An array of several telescopes may be required to provide ~10 sec cadence images in multiple temperatures required to understand rapid heating and cooling. In any event, intercalibration of intensity between the images to ~10% is necessary to derive sufficiently accurate physical characteristics in important features, and sufficient dynamic range in each temperature range should be provided to measure the full range of emission and absorptions features exhibited by the dynamic Sun. The field of view of the AIA in appropriate temperature regimes should extend well above the limb to facilitate linkage with white-light coronagraph observations. The spectral resolution of the images should be sufficiently narrow to separate the physically important temperature ranges.

Pursuant to this letter of Agreement, the PPARC will use reasonable efforts to carry out the following responsibilities:

1. Provide six development units and ten flight unit CDs
2. Provide one brassboard and one flight camera electronics box
3. Provide interface documentation
4. Provide ground support equipment to support the provided flight and development unit
5. Provide design and specification details
6. Support technical interchange meetings
7. Participate in test programs at NASA-funded contractor facilities
8. Provide support for the PPARC Co-Investigators

NASA and the PPARC-funded institutions will provide, on occasion, as appropriate, for personnel to visit one another's facilities to participate in integration and testing, and to observe, confer and advise the other Party in regard to aspects of design and development of compatible instrument interfaces, integration, and testing.

POINTS OF CONTACT

The NASA point-of-contact for this program is

Dr. Dana A. Brewer
Program Executive
Advanced Technology and Mission Studies Division
Office of Space Science, Code SM
NASA Headquarters
Washington, DC 20546
Telephone: 202-358-1678
Facsimile: 202-358-2697

The GSFC point-of-contact for this mission is:

Mr. U. Schwer
SDO Program Manager
Goddard Space Flight Center
Greenbelt, MD 20771
Telephone: 301-286-3225
Facsimile: 301-286-1690

The PPARC point-of-contact for this program is:

Dr. Graham Brooks
Particle Physics and Astronomy Research Council
Polaris House
North Star Avenue
Swindon Wiltshire SN2 1 SZ

United Kingdom
Telephone: 44 1793 442019
Fax: 44 1793 442036

The point-of contact at the Mullard Space Science Laboratory is:

Dr. J. Leonard Culhane
Director, MSSL and Head, Dept. of Space and Climate Physics
Mullard Space Science Laboratory
Holmbury St. Mary
Dorking
Surrey RH5 6NT
United Kingdom
Telephone: +44 0 1483 274111
Facsimile: +44 0 1483 278312

The point-of-contact at the Rutherford Appleton Laboratory is:

Dr. James Lang
Rutherford Appleton Laboratory
Chilton Didcot
Oxfordshire, OX11 0QX
United Kingdom
Telephone: +44 0 1235 44 6364
Facsimile: +44 0 1235 44 5848

FINANCIAL ARRANGEMENTS

Each Party will bear the costs of discharging its respective responsibilities, including travel and subsistence of its own personnel and transportation of all equipment for which it is responsible. It is understood that the ability of the Parties to carry out their obligations is subject to the availability of funds.

DATA RIGHTS

The Parties have access to and use of the scientific data generated under this Agreement. In accordance with criteria established in the NASA solicitation for science participation in the SDO mission, the SDO data will be treated as a public resource and will be made available for public access as soon as is practical. After the initial check out and calibration period of approximately 3 months after initial operation, the SDO database and requisite basic analysis software will be made available to the international community through a NASA data center. After the initial period, the data will be made public with no more than a two-month delay.

EXCHANGE OF TECHNICAL DATA AND GOODS

The Parties are obligated to transfer only those technical data (including software) and goods necessary to fulfill their respective responsibilities under this Agreement, in accordance with the following provisions:

1. The transfer of technical data for the purpose of discharging the parties' responsibilities with regard to interface, integration, and safety shall normally be made without restriction, except as required by national laws and regulations relating to export control or the control of classified data. If design, manufacturing, and processing data and associated software, which is proprietary but not export controlled, is necessary for interface, integration, or safety purposes, the transfer shall be made and the data and associated software shall be appropriately marked.
2. All transfers of proprietary technical data and export-controlled goods and technical data are subject to the following provisions. In the event a Party finds it necessary to transfer goods which are subject to export controls or technical data which is proprietary or subject to export control, and for which protection is to be maintained, such goods shall be specifically identified and such technical data shall be marked with a notice to indicate that they shall be used and disclosed by the receiving Party and its related entities (e.g., contractors and subcontractors) only for the purposes of fulfilling the receiving Party's responsibilities under the programs implemented by this Agreement, and that the identified goods and marked technical data shall not be disclosed or retransferred to any other entity without the prior written permission of the furnishing party. The receiving party agrees to abide by the terms of the notice, and to protect any such identified goods and marked technical data from unauthorized use and disclosure, and also agrees to obtain these same obligations from its related entities prior to the transfer.
3. All goods, marked proprietary data, and marked or unmarked technical data subject to export control, which is transferred under this Agreement, shall be used by the receiving party exclusively for the purposes of the programs implemented by this Agreement.
4. Title to all hardware to be exchanged under this Agreement will be retained by the party providing the item.

INVENTION AND PATENT RIGHTS

Nothing in this Agreement shall be construed as granting or implying any rights to, or interest in, patents or inventions of the Parties or their contractors or subcontractors.

All equipment and technical data transferred by the Parties under this Agreement shall remain the property of the originating Party unless specified otherwise in this Agreement. In accordance with its laws and regulations, each Party shall facilitate free customs clearance and waiver of all applicable customs duties and taxes for equipment and related goods necessary for the implementation of this Agreement. In the event that any customs duties or taxes of any kind are nonetheless levied on such equipment and related goods, such customs duties or taxes shall be borne by the Party of the country levying such customs duties or taxes. The Parties' obligation to ensure duty-free entry and exit of equipment and related goods is fully reciprocal.

LIABILITY AND RISK OF LOSS

With regard to activities undertaken pursuant to this Agreement, neither Party shall make any claim against the other, employees of the other, the other's related entities (e.g., contractors, subcontractors, investigators, or their contractors or subcontractors), or employees of its related entities, or for damage to or loss of its own property or that of its related entities, whether such injury, death, damage or loss arises through negligence or otherwise, except in the case of willful misconduct.

The Parties further agree to use all reasonable efforts to extend this provision as set forth above to their own related entities by requiring them, by contract or otherwise, to waive all claims against the other Party and its related entities against any claim for injury, death, damage or loss arising from activities undertaken pursuant to this Agreement.

This cross-waiver of liability shall not be applicable to:

1. Claims between a Party and its own related entity or between its own related entities;
2. Claims made by a natural person, his/her estate, survivors or subrogates for bodily injury, other impairment of health, or death of such natural person;
3. Claims for damage caused by willful misconduct;
4. Intellectual property claims;
5. Claims for damage based upon a failure of the Parties to extend the provision as set forth above or from a failure of the Parties to ensure that their related entities extend the provision as set forth above; or
6. Contract claims between the Parties based on express contractual provisions.

Nothing in this section shall be construed to create the basis for a claim or suit where none would otherwise exist.

CUSTOMS CLEARANCE

NASA and PPARC will arrange for timely, free customs clearance of equipment and data required for this project. In the event that any customs duty, fees and/or taxes of any kind are levied by the governments of the Parties on the equipment and related goods for the execution of this Agreement, and after seeking the necessary free customs clearance and waiver of applicable customs duties and taxes, such customs duty, fees and/or taxes shall be borne by the Party of the country levying the customs duty, fees and/or taxes. Such arrangements shall be reciprocal and in accordance with the respective national laws and regulations of the Parties.

PUBLIC INFORMATION

Release of public information regarding this program may be made by the appropriate agency for its own portion of the program as desired and, insofar as participation of the other is involved, after suitable consultation.

CHOICE OF LAW

The parties hereby designate the U.S. Federal law to govern this Agreement for all purposes, including, but not limited to, determining the validity of the Agreement, the meaning of its provisions, and the rights, obligations, and remedies of the Parties.

ENTRY INTO FORCE AND TERMINATION

This Letter of Agreement will go into effect upon the date of PPARC affirmative reply. It will remain in force for the duration of the SDO mission including data analysis and archiving, or until SDO is on station two years. It may be extended or amended by mutual written agreement of the Parties. This Agreement can be terminated by NASA or PPARC after six months' written notice of its intention to terminate the Agreement.

If the above terms and conditions are acceptable to PPARC, we propose that this letter, together with your affirmative reply, document our joint understanding as to the implementation of this cooperative effort.

Sincerely,

P. Diane Rausch
Director
Space Science and Aeronautics Division
Office of External Relations

G8 INTERNATIONAL PARTICIPATION AND EXPORT CONTROL

Introduction

The Lockheed Martin Corporation and (LM) Lockheed Martin Space Systems Company—Missiles & Space Operations (LMSSC—MSO) are committed to comply with the International Traffic in Arms Regulations (ITAR) and the Arms Export Control Act (AECA). We have declared our commitment in Corporate Policy Statement (CPS) 601 and in MSO Enterprise Management Policy 2.35-2.

The Solar & Astrophysics Department has extensive experience working with international participants on a wide array of successful programs including Yohkoh, MDI, Solar-B/FPP, and STEREO/SECCHI. On AIA we plan to team with some of the same international partners who helped to make our past programs successful. As necessary, we will apply for Technical Assistance Agreements (TAA) in a timely manner to ensure we meet our program cost and schedule.

We back up our commitment to ITAR compliance by providing significant resources both to train our people and to implement systems and processes that ensure the proper transfer of technical data and defense services. We also conduct thorough audits to ensure compliance with our TAAs, Export/Import licenses, and Technology Transfer Control Plans (TTCP).

Management

The AIA program management team and the LMATC Export/Import Licensing and Compliance Manager, in conjunction with the Missiles and Space Licensing Office staff, work together to ensure that appropriate Export/Import License and Compliance resources are applied to each phase of the program. We also provide assistance to our subcontractors, vendors and our domestic teammates to ensure that AIA is fully compliant with export regulations.

The Lockheed Martin Corporate Export/Import Office (LMCEIO) reviews all license applications for accuracy, completeness, and conformance with the ITAR before submitting them to the Office of Defense Trade Controls (ODTC); and works any issues that may arise during the ODTC license approval process so that delays are minimized. The LMCEIO intercedes on our behalf to bring problems to rapid closure and has daily contact with the ODTC. Our LMCEIO also provides sound export management advice on the current regulatory environment.

Training

Comprehensive training is fundamental to effective ITAR compliance. The LMSSC-MSO export education and training program provides AIA personnel with the tools and knowledge to effectively comply with their export responsibilities, laws and regulations. Export training is supported by the LMSSC-MSO President and executive management team as administered by the Export/Import Licensing & Compliance Office (EILCO), which reports to the LMSSC—MSO Vice President and General Counsel’s office.

Following the AIA program award, all AIA personnel will receive initial or refresher AIA Export/Import Licensing & Compliance (EILC) training. There is a generalized training session covering the ITAR, AECA compliance, and a broad range of Export/Import Licensing and Compliance topics. Advanced training sessions focus specific attention on each AIA TAA. The advanced training covers the Limitations & Provisos, the TTCP, and the role the US Government plays in the licensing of defense articles and services. At the conclusion of the general training session, all attendees sign Non-Disclosure Agreements certifying that they understand the ITAR and AECA. For the advanced training sessions, the attendees further certify that they understand the Limitations and Provisos, and the TTCP if applicable.

Audits

We conduct periodic internal audits to assess the effectiveness of our training, identify areas of weaknesses, and implement improvements to our training and processes. These audits are conducted by EILCO, which reports directly to the Vice President and General Counsel of LMSSC-MSO. To ensure impartiality, the Chief Counsel may retain outside counsel to assist in conducting independent audits. Corporate Audits are also conducted to ensure compliance with corporate policies and procedures and with applicable United States Laws and Regulations.

In March 2001, Lockheed Martin Corporation audited LMSSC – MSO; and we received a satisfactory result. For such internal audits, a satisfactory result is a passing mark.

In May 2001, DoD/DTSA performed an audit and we were given a very satisfactory result. It should be noted that the USG also grades conservatively, and very satisfactory results are an exception.

In July 2001, we received a Pre-Department of State ODTC audit; and again we were given a satisfactory grade. It means there were no major deficiencies, and any issues identified were minor in nature.

In December 2001, the Department of State ODTC audited LMSSC-MSO again. We are awaiting the results of that audit.

The limitations and provisos can be a barometer of compliance with both the ITAR and provisions of previous licenses. We have most recently been successful in receipt of more lenient limitations and provisos, than the rest of industry; which is a direct reflection of ODTC's trust in LMSSC-MSO.

Lockheed Martin Automated Support Systems:

Lockheed Martin Corporation has made significant investments in export licensing support systems so that we may efficiently integrate, manage, and provide our employees with accurate and efficient access to the export licensing and compliance requirements for our international activities. Our systems collect the required data files from servers and integrate them into relational databases, allowing us to manage work processes with significantly improved efficiencies.

We have three main systems that we use to manage our licenses and technical information:

- **Export Import Compliance & License Processing System** (ECLPS) – An automated license application system;
- **License Management System** (LMS) – An automated database tool powered by the 4-D relational database for tracking License Applications, releasing Licenses for Use, and maintaining licenses in compliance with ITAR regulations; and
- **Export Document Control System** (EDCS) – A data transfer and archiving tool that allows secure electronic transfer of large files of technical data over a virtual private network (VPN) to the U. S. Government as required and archives the files in a technical data library by license number for easy reference of exported data.

The benefit of these systems is their accessibility. They are available on the PC desktop and have graphical user interfaces (GUI) that permit navigation through the systems to quickly and efficiently process the export of technical data. These systems also have levels of security that protects the data from being "hacked" by unauthorized sources.

Proposed International Participation

The AIA investigation will involve foreign participation in the hardware development phase of the program and in the science preparation and scientific analysis of data acquired post launch. Several of the co-investigators will be solely involved in the analysis of SDO data, which being in the public domain, are exempted from the need for a TAA. If we later discover that it is necessary to transfer export-

Table G8-1. *AIA Co-Investigators for which TAAs will be required.*

Company	Nationality	Effort	LM Prior Experience
Mullard Space Science Laboratory	UK	Procure and characterize CCD detectors	OSO-8, SMM, Aries XRT, SXI, FPP
Rutherford Appleton Laboratory	UK	Provide CCD cameras	SMM, STEREO
Marconi Aplpied Technology, Ltd	UK	Manufacture CCD detectors	SXI, FPP, STEREO

controlled information to these co-investigators, we will seek TAAs as required.

The CCD detectors and the CCD camera system will be provided by three groups in the UK: Mullard Space Science Laboratory, Rutherford Appleton Laboratory, and Marconi Advanced Technologies, Ltd (see Table G8-1). It will be necessary to obtain the prior approval of the Department of State via a technical assistance agreement to transfer technical data to these parties. Therefore, upon notification of selection for the SDO mission, LM will prepare TAAs in a timely manner with these UK partners to avoid cost and schedule impacts to the AIA program. The TAA application will define what technical data will be controlled along with a definition of the specific flight hardware that will be imported or exported. The TAA will also define any defense services that would be necessary under the terms of the NASA contract.

Summary

The purpose of our compliance program is to ensure all transfers of technology to foreign parties are in compliance with all applicable laws and regulations. Our compliance programs seeks to make an impartial assessment of our performance in three major areas: Export systems (which includes our License Management System and our Export Document Control System), employee training and subcontractor education. Our commitment is to increase and sustain awareness, to protect our technology, and to abide by the letter and intent of export laws and regulations. To achieve this objective, we have implemented a comprehensive licensing and compliance system. The implementation of this program is the responsibility of the Export/Import Licensing & Compliance Office (EILCO), who coordinates all aspects of export/import licensing and compliance in direct support of the AIA Program. In addition, we have trained program personnel who act as the “eyes and the ears” for ITAR related issues, as liaisons to EILCO, so that export related matters are prioritized and addressed as soon as they are identified.

The EILCO is dedicated to ensure all ITAR issues are handled quickly, correctly, and completely. Through this proposal solicitation we have detailed our plans for supporting the Export Import requirements of the AIA program. Through our Licensing and Compliance policies and utilization of our automated systems resources, we will ensure that the AIA program conducts all business with our international partners in compliance with US Government Export Regulations without disruption to the technical, cost, and schedule objectives of the AIA program.

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